An improved Eigen-value/Eigenvector based Land Cover Classification for high entropy areas

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Abstract— Polarimetric SAR (Synthetic Aperture Radar) is known as a powerful tool to observe surface of the earth and to extract the quantitative bio-physical and geo-physical information. Hence target decomposition theorems are introduced to establish the co-relation between SAR measured values and the parameters representing physical significance of scattering mechanisms and associated mediums. Target decomposition theorems exploit the information contained in the coherency matrix T_3 or covariance matrix C_3.

The proposed work deals with exploitation of information contained in PolSAR coherency matrix through eigen value-based decomposition techniques. The major issue associated with eigen value-based decomposition techniques is inefficiency of H/α/A decomposition to classify high entropy areas. The well-known entropy-alpha method has alpha angle instability at medium and high entropy (H) areas. At medium and high entropy, the scattering mechanism cannot be correctly estimated. When $H > 0.7$ and alpha angle reaches 60°, the feasibility of H/α/A decomposition shrinks. Therefore, other eigen value-based parameters should be considered at medium and high entropy areas.

The proposed work uses SERD (Single bounce eigen value relative difference) and DERD (Double bounce eigen value relative difference) parameters for improved classification. We replaced alpha angle with SERD/DERD parameters as a classification criterion in entropy-alpha decomposition. The proposed algorithm is compared with entropy-alpha decomposition and improved classification is obtained, especially at high entropy areas.

The proposed algorithm is implemented on L-band San Francisco bay (NASA/JPL AIRSAR data). The proposed algorithm is able to classify forest area correctly at high entropy values ($H > 0.7$).

Keywords- SAR, Polarimetry, Coherency matrix, Covariance matrix, SERD, DERD.

I. INTRODUCTION

The earth surface modification should be planned properly. For that purpose, the land cover must be monitored geographically and quantitatively. Microwave imaging must be preferred to optical imaging because of weather independent and all time(day-night) imaging of the complete surface of the earth, which is quite impossible by optical imaging(specially in night).

The sensitivity of microwave radiation towards dielectric properties and geometrical architecture of the natural and artificial target causes microwave remote sensing a tedious task for significant number of applications. To extract and evaluate the data related to earth surface effectively and accurately is still a challenging job for radar remote sensing.

The conventional radar systems were direct aperture radars, in which information about the target were consider only in the form of magnitude, and phase information was ignored due to use of single fixed polarization antenna for reception as well as transmission. In such type of system, for every resolution cell single backscattering coefficient was measured using a particular combination of transmits and receives polarization states in order to measure radar echo. Therefore, target identification was not possible because of the backscattered signal received for different target having same intensity.

The development of SAR (Synthetic Aperture Radar) sensors was a revolution in this field. SAR sensor being a polarization sensitive instrument considers full vector nature of electromagnetic wave. Synthetic Aperture Radar records both amplitude information as well as phase information of the target.

The proposed work uses SERD (Single bounce eigen value relative difference) and DERD (Double bounce eigen value relative difference) parameters for improved classification. We replaced alpha angle with SERD/DERD parameters as a classification criterion in entropy-alpha decomposition*[1]*. The proposed algorithm is compared with entropy-alpha decomposition and improved classification is obtained, especially at high entropy areas.

II. COHERENCY AND COVARIANCE MATRICES

The extraction of the information from the scattering matrix (S) has been achieved through the system vectors.

We present the Sinclair matrix as,

$$S = \begin{bmatrix} S_{XX} & S_{XY} \\ S_{YX} & S_{YY} \end{bmatrix}$$

The Coherency matrix *T*, conveying the relation between scattered signals in the channels of a radar polarization defined as,

$$T_3 = \frac{1}{2}\begin{bmatrix} \langle |S_{XX}+S_{YY}|^2\rangle & \langle (S_{XX}+S_{YY})(S_{XX}-S_{YY})\rangle & 2\langle (S_{XX}+S_{YY})S_{XY}^{*}\rangle \\ \langle (S_{XX}-S_{YY})(S_{XX}+S_{YY})^{*}\rangle & \langle |S_{XX}-S_{YY}|^2\rangle & 2\langle (S_{XX}-S_{YY})S_{XY}^{*}\rangle \\ 2\langle S_{XY}(S_{XX}+S_{YY})^{*}\rangle & 2\langle S_{XY}(S_{XX}-S_{YY})^{*}\rangle & 4\langle |S_{XY}|^2\rangle \end{bmatrix}$$

The elements of coherency and covariance matrices are extensively used to extract various parameters which are helpful for target classification. Both matrices are hermitian positive semi-definite and have same eigen values. Target decomposition theorems used to extract the information from coherency or covariance matrix are categorized under incoherent decomposition techniques.

The incoherent decomposition techniques may be classified into two main categories, viz. model-based decomposition techniques and eigen value based decomposition techniques. The pioneer eigen value/eigen vector based and model-based techniques are entropy/alpha/anisotropy decomposition*[1]* and Freeman-Durden three-component decomposition*[2]* respectively.

III. EIGEN VALUE/EIGEN VECTOR BASED DECOMPOSITION

The eigen values and eigenvectors of the coherency matrix can be calculated to generate a diagonal form of coherency*[3]* matrix as,

$$T_3 = U_3 \Sigma U_3^{-1}$$

where Σ is a 3×3 diagonal matrix with eigen values $(\lambda_1, \lambda_2, \lambda_3)$ as its diagonal elements $(\lambda_1 \geq \lambda_2 \geq \lambda_3)$ and U_3 is a 3×3 unitary matrix as $U_3 = [\underline{u_1} \;\; \underline{u_2} \;\; \underline{u_3}]$ where $\underline{u_1}$, $\underline{u_2}$ and $\underline{u_3}$ are the orthogonal eigenvectors.

The proposed work deals with exploitation of information contained in PolSAR coherency matrix through eigen value based decomposition techniques. In entropy/alpha/anisotropy decomposition, entropy (H) defines degree of randomness, alpha (α) angle defines dominant scattering mechanism whereas anisotropy (A) defines relative importance of second and third eigen values.

III A. Entropy, Alpha angle And Anisotropy Parameters

The eigenvector based decomposition can be written as,

$$T = \sum_{i=1}^{3} \lambda_i \underline{u}_i \cdot \underline{u}_i^{*T}$$

Where λ_i and $\underline{u}_i$ are the eigen values and eigenvectors of the coherency matrix respectively. $\underline{u}_i$ can be written as,

$$\underline{u}_i = e^{j\varphi_i}[cos\alpha_i \quad sin\alpha_i cos\beta_i e^{j\delta_i} \quad sin\alpha_i sin\beta_i e^{j\gamma_i}]^T$$

Where alpha angle(α) corresponds to different scattering mechanisms, β angle is twice of polarization orientation angle, φ is the equivalent to target absolute phase, and δ and γ are the phase differences of second and third terms relative to the first term. The alpha angle (α) can be related directly to underlying physical scattering mechanisms. Low alpha angle corresponds to the surface scattering while the vegetation and urban area consist of medium and high α values (45°<α<90°).

The entropy (H) is considered as degree of randomness for scattering mechanism. For pure target case, entropy is equal to 0, while for distributed target, entropy is equal to 1. The third case lies between the two i.e. for partial target, the entropy is in between 0 to 1.

Anisotropy comes into picture only in case of high entropy areas (H>0.7). Anisotropy defines relative importance of 2nd and 3rd eigen values. Taking into consideration the eigen values of coherency/covariance matrix from largest to smallest as,

$$\lambda_1 > \lambda_2 > \lambda_3$$

Anisotropy can be defined as,

$$A = \frac{\lambda_2 - \lambda_3}{\lambda_2 + \lambda_3}$$

As observed from polarimetry data, ocean region & parkland areas show low anisotropy and urban & coastal areas show a mixture of medium & high anisotropy which clearly indicates the importance of anisotropy for land cover classification.

III B. Entropy- Alpha Classifiaction

S. R. Cloude and E. Pottier proposed 'Entropy-Alpha' decomposition*[1]* by using the eigen values and eigenvectors of the coherency matrix. They defined that each pixel of the image will have a dominant scattering mechanism. In this, they used San Francisco AIRSAR data set and further categorized it into three types of scattering mechanisms (surface, double bounce & volume scattering) by using alpha angle. Then they further set the entropy as a dimension (low, medium & high) to categorize H/α plane into nine zones.

The categorization proposed by them proved to be reliable at low entropy values but failed miserably to effectively categorize terrain at medium and high entropy areas. It has alpha angle instability at medium and high entropy areas. At medium and high entropy, the scattering mechanism cannot be correctly estimated. When H > 0.7 and alpha angle reaches 60°, the feasibility of H/α/A decomposition shrinks. Therefore, other eigen value-based parameters should be considered at medium & high entropy areas.

As we can see that anisotropy is using 2nd largest eigen-value (λ_2), not the largest eigen value (λ_1). Because of not utilizing the largest eigen-value (λ_1), anisotropy is unable to classify high entropy areas.

IV. PROPOSED DECOMPOSITION METHOD

The proposed work uses SERD (Single bounce eigen value relative difference) and DERD (Double bounce eigen value relative difference) parameters for improved classification. We replaced alpha angle with SERD/DERD parameters as a classification criterion*[4]* in entropy-alpha decomposition. The proposed algorithm is compared with entropy-alpha decomposition and improved classification is obtained, especially at high entropy areas.

The SERD parameter is close to one for dominant surface scattering and occupies lower values for dominant volume scattering. DERD parameter is close to one for dominant double bounce scattering.

The proposed algorithm is implemented on L-band San Francisco bay (NASA/JPL AIRSAR data) which is a hybrid area composed of sea surface, vegetation area and mixed urban region. Entropy-alpha decomposition miss-classifies some of the forest area as double bounce scattering at high entropy areas. The proposed algorithm is able to classify forest area correctly at high entropy values (H>0.7). Also some of the sea-sore areas are miss-classified as volume scattering in entropy-alpha decomposition which is classified accurately in proposed algorithm.

IV A. SERD And DERD Parameters

S. Allain *et al.[4]* derived two novel polarimetric parameters known as SERD (Single bounce Eigen value Relative Difference) & DERD (Double bounce Eigen value Relative Difference). These parameters combining together cover entire eigen value spectrum and hence can be utilized for the comparison of various scattering mechanisms. The above parameters are derived for natural mediums considering reflection symmetry hypothesis.

To determine dominant scattering, alpha angle is slightly modified as shown below.

$$\alpha_1 = \tan^{-1}\frac{|S_{hh}-S_{vv}|}{|S_{hh}+S_{vv}|}$$

$$\text{SERD} = \frac{\lambda_S-\lambda_3}{\lambda_S+\lambda_3}$$

$$\text{DERD} = \frac{\lambda_D-\lambda_3}{\lambda_D+\lambda_3}$$

The orthogonal condition is considered between the two alpha angles (α_1 & α_2), as shown below.

$$\alpha_1 + \alpha_2 = \frac{\pi}{2}$$

If $\alpha_1 > \frac{\pi}{4}$, $\alpha_2 < \frac{\pi}{4}$, then $\lambda_S = \lambda_2$ and $\lambda_D = \lambda_1$.

If $\alpha_1 < \frac{\pi}{4}$, $\alpha_2 > \frac{\pi}{4}$, then $\lambda_S = \lambda_1$ and $\lambda_D = \lambda_2$.

Case 1: $\alpha_1 >= \pi/4$, for this case all the pixels having alpha angle more than 45° will be represented by DERD and hence will have dominant double bounce scattering.

Case 2: $\alpha_2 < \pi/4$, for this case all the pixels having alpha angle less than 45° will be represented by SERD and hence will have dominant either single bounce scattering or volume scattering according to boundaries set by SERD parameter.

IV B. Algorithm of H/SERD/DERD Decomposition

Step 1: Classify the selected area in accordance with alpha angle for dividing pixels into three types of dominant scattering mechanisms.
Step 2: After that entropy was used to categorize areas within each scattering mechanism into low, medium and high entropy classification.
Step 3: For areas dominated by volume scattering, compare SERD & DERD parameter.
Step 4: If DERD is greater than or equal to SERD, then classify that area as dominant double bounce scattering instead of volume scattering.
Step 5: If SERD is greater than DERD, then retain that area as dominant volume scattering with SERD values from 0 to 0.7.
Step 6: If SERD is greater than DERD, then classify that area as dominant surface scattering with SERD values from 0.7 to 1.

V . Implementations, Results And Discussion

H/SERD/DERD v/s Entropy Alpha decomposition

The proposed algorithm is implemented on L-band San Francisco bay (NASA/JPL AIRSAR data) which is a hybrid area composed of sea surface, vegetation area and mixed urban region.

Fig 1.Pauli RGB image

Fig 2.without SERD/DERD

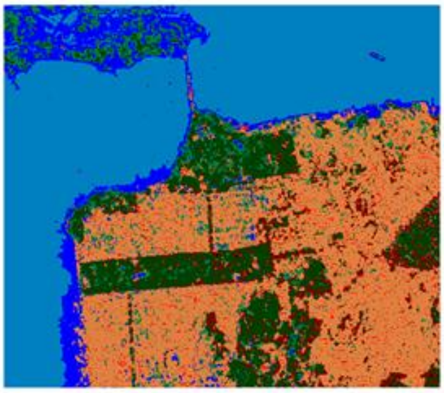


Fig 3.with SERD/DERD

The feasibility of eigen value decomposition starts to shrink when entropy becomes greater than 0.7, Hence H/SERD/DERD decomposition is compared with Entropy-Alpha decomposition at entropy (H) > 0.7 and results are shown below.

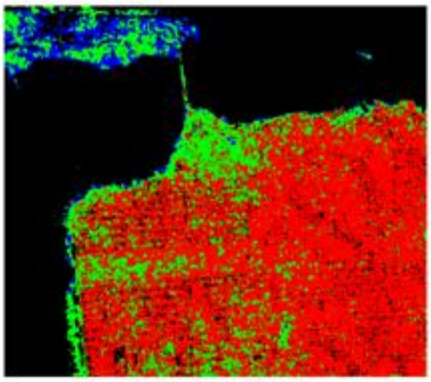
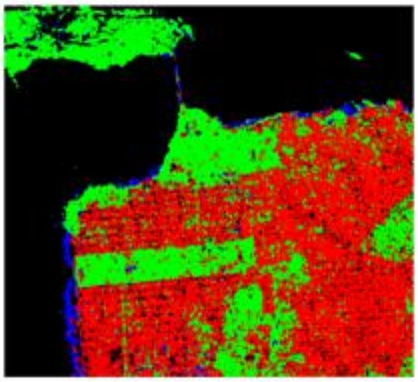


Fig 4. i)H/α decomposition(H>0.7)



ii)Proposed decomposition(H>0.7)

As seen above, the proposed method is able to classify urban area properly at high entropy values(H>0.7). The colour assignment followed is blue, red and green for single bounce, double bounce and volume scattering respectively. The entropy-alpha decomposition miss-classified forest area as double bounce scattering at high entropy areas, but the proposed decomposition classifies forest area correctly. The areas with entropy less than 0.7 are not assigned any colour and hence represented by black colour.

Hence the proposed classification can be used for oriented urban area classification and thus can avoid the need of oriented angle compensation as SERD/DERD are roll invariant parameters.

VI. CONCLUSION AND FUTURE SCOPE

The current scenario demands extensive use of radar polarimetry in the area of land cover classification and post data acquisition analysis. To serve the purpose, already developed coherent and incoherent decomposition techniques are present which are widely used. But the flaws in existing techniques demand more efficient and novel techniques.

In the view of this, the attempt has been made to overcome the drawbacks and to improve the efficiency of current decomposition techniques. The major drawbacks and problem statements are discussed. The adaptive algorithms confined to a particular limitation are implemented and results are discussed.

The inclusion of SERD (Single bounce eigen value relative difference) and DERD (Double bounce eigen value relative difference) parameters in proposed algorithm increases classification efficiency in significant amount and a detailed comparison is proposed and discussed.

The possible future work may include analysis of high entropy single bounce zone in entropy-alpha decomposition which is still not classified yet. Also the use of scattering information along with statistical data may provide better results.

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References

[1] S. R. Cloude and E. Pottier, “An Entropy Based Classification Scheme for Land Applications of Polarimetric SAR,” IEEE Trans. Geosci. Remote Sensing, vol. 35, pp. 68–78, January 1997.

[2] A. Freeman and S. L. Durden, “A three-component scattering model for polarimetric SAR data,” IEEE Trans. Geosci. Remote Sensing, vol. 36, pp. 963–973, May 1998.

[3] S. R. Cloude and E. Pottier, “A review of target decomposition theorems in radar polarimetry,” IEEE Trans. Geosci. Remote Sensing, vol. 34, pp.498–518, Mar. 1996.

[4] S. Allain, L. Ferro-Famil, E. Pottier, New eigenvalue-based parameters for natural media characterization, University of Rennes 1, I.E.T.R, UMR CNRS 6164, Image and Remote Sensing Group.