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# Entropy Based Target Identification in Synthetic Aperture Radar Polarimetry

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***Abstract—Synthetic aperture radar is used for polarimetric target identification. It is most prominent imaging radar. This radar covers the widest ranges of earth crust with high resolution images. It captures images day and night. It is suitable for any seasonal weather conditions. The polarization data contains information, on scattering mechanism related to different objects. The objects are land, ocean, glaceries, snow and dense forest which are natural distributed targets. By the use of scattering mechanism the different objects are classified. Scattering mechanism is measured by scattering elements of the matrix. The full polarization of synthetic aperture radar data classifies the obtained image. This paper analyses an entropy based target identification related to synthetic aperture radar polarimetry. The method is also the outcome of Eigen decomposition analysis. The paper also gives broader view of identification of target using physical property and analytical model. The method is helpful for system level design and scattering process considerations.***

***Keywords—Synthetic Aperture Radar, Polarimetry, Eigen, Decomposition, Entropy, Coherency matrix***

## I. INTRODUCTION

To identify targets efficiently advanced airborne and space borne Synthetic Aperture Radars (SAR) are designed and developed. In this radar the two platforms that is sensor and target region both are in relative motion. The SAR processing unit is mounted on a moving system basically aircraft or space craft. The target is covered by single beam by the radar antenna. The target area is continuously illuminated with pulses of radio waves, at wave lengths meters to mm. The obtained synthetic radar image can be classified by the full polarization information of the synthetic aperture radar data. The accessing of full polarization is the basic technique behind the SAR polarimetry. It is a method to obtain the target details which is basically based on amplitude and phase related information. The term full polarization refers to the four main channels used in quad (full) polarimetry. They are polarized in four directions namely horizontal -horizontal (HH), horizontal -vertical (HV), vertical horizontal (VH) and vertical – vertical (VV) directions.

The scattering mechanism describes the physical details of the target. The physical details of the target are referenced to its dielectric constant and orientation. It is obtained through various scattering mechanisms. The radar SAR sensor transmits continuously the electromagnetic wave towards the target. In response to incident wave the various echo waveforms are received by the receiving antenna. At several different antenna positions, the target is detected with coherency. The received signals are called as echo signals. The scattering matrix representing the information of echo signals has the four basic elements $S_{HH}$, $S_{HV}$, $S_{VH}$, $S_{VV}$.

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The properties of individual objects of the earth surface are characterized by their own scattering nature. This scattering nature is represented mathematically as the scattering matrix for each pixel of the target image. The received signal obtained by SAR sensor adds for criteria called resolution cell. It is basically the resultant criteria of many distributed targets. These targets are distributed in spatial form. Every individual or target is represented by different types of scattering mechanisms. The various scattering mechanisms involved are surface scattering also known as single bounce scattering. The other mechanisms are typically known as double bounce, volume and helix scattering. These are obtained by the natural targets and manmade targets. The physical property surface roughness and its materialistic property namely dielectric constant decide which type of scattering mechanisms occurs. The feature called coherent is basic element criteria of the scattering matrix. It means that the terms in off diagonal element of scattering matrix that is $S_{HV}$ and $S_{VH}$ are equal. Scattering matrix normally gives the detail idea of the working pattern of radar system, in hitting the particular target on the earth surface. It also describes the behavior of the targets on the earth surface for the feature called scatter. This represents the electromagnetic energy returned back towards the radar sensor.

While evaluating the image information the dimension of the S matrix is considered as 2*2. It is hence considered for every pixel of an image. This concept is illustrated by the authors Fawag Ulaby and Ehsrlon Elactic in contribution toward their paper radar polarimetry for geo science applications [2]. The responses obtained by two same points always have minimum observable spacing which contributes for resolution. This is again applied to width of one more response other than previous two. A weaker response among them basically requires larger separation for the detection of the target. Each resolution cell is represented by two pixels. Pixel spacing in SAR imagery is considered for some standard scale. It is normally taken as multiple or division of 100 mts. For ex. ERS -1 data has resolution of 28 mts. In range and azimuth it is delivered with 12.5 mt pixel spacing. In SAR image, the direction of aircraft or space craft is called azimuth direction. The imaging direction is called range direction. SAR processing involves range focusing and azimuth focusing. Range focusing involves de-chirping of received echoes. Azimuth focusing relies on Doppler information produced by target. The difference in dimension of pixel of signal related to SAR image exists to the resolution cell during the data acquisition. It is due to variation of range resolution angle. So pixel resampling is carried out with uniform grid.

The information obtained by SAR polarimetry refers to the data of polarization state of received signals. It is represented for every resolution element or pixel. The behavior of the target is a mathematical representation which is modeled in terms of scattering matrix.

This is basically the information of electromagnetic wave reflected by the objects. Current airborne systems have an azimuth resolution of 1m to 0.5m. The resolution of image gives the separation between closest surfaces, which is basically resolved in the final image. The authors in [14] [16] explain with illustrative figures the concept of SAR resolution.

. The recent advances in SAR polarimetry features the fundamentals of processing SAR data using mathematical model in an organized way [7]. Polarimetry is the study of measurement and investigation method of the polarization pattern of transverse electromagnetic waves. These EM waves are also known as radio or light waves. Polarimetry is carried out on such electromagnetic waves, which are already are reflected or refracted or diffracted waves. These reflection or refraction or diffraction will occur through some material. This change in features will characterize the particular object. Depending on the data received by acquisition method various processing techniques are followed. The processing of SAR data is limited by processing of intensity from target image acquired. The Interferometric processing involves intensity and interferometric phase processing. In interferometry phase and intensity are the main parameters. The target image is processed using various techniques. In interferometry only one image is acquired featuring phase and intensity. In polarimetry the data acquisition is done using different polarization techniques.

Polarimetric processing involves intensity and polarimetric phase processing. In [1][15] the authors illustrate the fundamental aspects of polarization. Polarization is the method of alignment of electric and magnetic field. These fields are the elementary components of Electromagnetic waves. Although these two fields illustrate the characterization of EM waves, its behavior can be solely done by using the electric field. This is possible because the electric and magnetic field has distinct mathematical relationship. Hence the entire EM wave can be investigated only by knowing the electric field vector. The electric field is represented as a vector. This vector has a length which distinctly represents the amplitude of the electromagnetic wave. The vector rotation rate gives the frequency of the wave. The vector movement can be in different directions namely linear, elliptical and circular. Polarimetric interferometric processing involves intensity, interferometric and polarimetric phase processing which is a new and advanced technique.

The radar frequency or wavelength, polarization and incidence angles affect the scattering mechanisms. If surface is found smooth the existence of depolarization is considered as nil. It implies HV or VH back scatter is not present. If the surface is rough then there will be some depolarization existing. Hence HV or VH backscatter exists. For volume scattering such as forest and vegetation high depolarization is found. Thus one can categorize various objects based on the scattering mechanisms. There is peculiar relation exist between scattering mechanisms, scattering matrix and various decomposition techniques involved in the SAR polarimetry. The section II highlights the importance of coherency matrices in the evaluation of Eigen decomposition for entropy based target identification.

## II. CO VARIANCE AND COHERENCY MATRICES

The scattering properties of a target are basically described by various forms of mathematical representation. The role precisely works when it comes to the power domain criteria. So the SAR image is identified with various matrices known as Coherency and Covariance matrix. The other forms of matrix are Muller, Stokes and Scattering matrix. The reflected wave from the target has different polarization in relation to incident wave of the radar sensor. The scattering matrix consists of 4 basic elements $S_{hh}$, $S_{hv}$, $S_{vh}$ and $S_{vv}$ which are complex in values. The response of the target is function of incident electromagnetic wave as well as back scattered polarizations. The scattering power can be determined by 4 polarization variables HH, HV, VH and VV, the incident angle, elipticity angle, orientation and reflected angles.

The interaction of electromagnetic wave with objects forms scattering mechanism related to objects. Polarimetric information of given pixel is representation of scattering mechanisms. To interpret this scattering mechanism and objects properties polarimetric decomposition models are developed. The two vectors called covariance vector and coherency vector plays the major role in forming the two specific matrices called as covariance matrix and coherency matrix. The covariance vector is represented by symbol $k_C$ . It is the vector representation of scattering matrix. It also forms the basis for linear decomposition technique of SAR polarimetry. The self multiplication of covariance vector and its conjugate transpose will lead to the formation of covariance matrix. The coherency vector is represented by symbol $k_T$ . This vector is basis for Pauli decomposition analysis. The elements of coherency vector describes the physical features of the target. Basically it depends on the type of scattering mechanism involved by the target. The self multiplication of coherency vector and its conjugate transpose will help in forming the coherency matrix. The section III describes the mathematical representation of the covariance and coherency matrix.

## III. MATHEMATICAL REPRESENTATION OF COHERENCY MATRIX

### *A. Covariance Matrix:*

The basic formation of this matrix is by target vector called as covariance vector denoted as $k_C$ .

$$k_C = \begin{bmatrix} k_1 \\ k_2 \\ k_3 \end{bmatrix} = \begin{bmatrix} S_{HH} \\ \sqrt{2} S_{HV} \\ S_{VV} \end{bmatrix} .......(1)$$

The elements $S_{HH}$ and $S_{VV}$ are the co polarized element. The $S_{HV}$ represents the cross polarized element. The reciprocity condition is satisfied by this vector. It indicates equivalence between $S_{VH}$ and $S_{HV.}$ The linear decomposition technique is considered as basic decomposition technique. Here information obtained from individual polarization channel is considered. The information obtained corresponds to cross polarized scatter. The three vectors are $k_1$, $k_2$ and $k_3$. The $k_1$ represents the scatter of horizontal oriented target scattering. The second component $k_2$ is by cross polarized scatter. The third component $k_3$ is scatter of vertical oriented target scattering. The covariance matrix is represented by C. It is obtained by multiplication of $k_C$ itself. T indicates transpose operation on $k_C$ .

$$C = k_C * k_C^{*T} .......(2)$$

### B. *Coherency matrix*

The vector called coherency vector is termed by $k_P$ . The vectorization is carried out in Pauli spin type. Here also the reciprocity condition is considered.

$$k_P = \begin{bmatrix} k_1 \\ k_2 \\ k_3 \end{bmatrix} = \frac{1}{\sqrt{2}} \begin{bmatrix} S_{HH} + S_{VV} \\ S_{HH} - S_{VV} \\ 2S_{HV} \end{bmatrix} .......(3)$$

The vector basically represents three main scattering mechanisms called odd bounce, even bounce and diffuse scattering. Pauli decomposition uses Pauli matrices for the extension of scattering matrix. It is basically applied to deterministic targets of consideration. It consists of four scattering mechanisms. The first is called single scattering from plane surface. The second and third parameter is called diplane scattering. It is also called as double or even bounce scattering. Such scattering will occur from corners with orientation of $0^0$ and $45^o$. The fourth element is called anti symmetric component of S matrix. For the monostatic radar this term leads to value zero.

The coherency matrix is represented by $T_{cohe}$. It is obtained by self multiplication of $k_P$

$$T_{cohe} = k_P * k_P^{*T} .......(4)$$

The two important decomposition method of SAR polarimetry called linear decomposition and Pauli decomposition can be obtained by using the two scattering vectors $k_C$ and $k_P$

The next section describes the importance of Eigen value decomposition which is the base for entropy based target identification.

## IV. ENTROPY BASED TARGET IDENTIFICATION

The coherency matrix contains information of the scattering process. It is a 3*3 Hermitian semi definite positive matrix [4]. The matrix is called positive definite if its Hermitian or symmetric part has positive Eigen values. This matrix can be written in the form of Eigen values.

$$T_{cohe} = \lambda_1 (e_1 . e_1^{\ T}) + \lambda_2 (e_2 . e_2^{\ T}) + \lambda_3 (e_3 . e_3^{\ T}) ........(5)$$

The mathematical equation represents the Eigen value decomposition of coherency matrix. The symbol $e_1$, $e_2$ and $e_3$ represents Eigen vectors. It involves the three basic scattering mechanisms known as surface, double bounce and volume scattering. The prominent parameters of Eigen value decomposition are scattering entropy (H), scattering Anisotropy (A) and mean scattering angle (α) and β. The entropy H characterizes the scattering mechanisms.

$$H = -\sum_{i=1}^{3} p_i \log_3 p_i ........(6)$$

$$A = \frac{\lambda_2 - \lambda_3}{\lambda_2 + \lambda_3} ........(7)$$

$$\alpha = p_1 \alpha_1 + p_2 \alpha_2 + p_3 \alpha_3 ........(8)$$

Entropy H and Anisotropy A are parameters related to eigenvalues $\lambda_1$, $\lambda_2$, $\lambda_3$ which are obtained from coherency matrix. The α and β are from Eigen vectors. The angle α describes the surface scattering and angle β is double of orientation angle.
Here probability $P_i$ obtained from Eigen value is given by,

$$p_i = \frac{\lambda_i}{\lambda_1 + \lambda_2 + \lambda_3} ........(9)$$

The entropy characterizes the feature of randomness involved through the scattering by the target.

$$T_{cohe} = k_p k_p^{*T} = \frac{1}{2} \begin{bmatrix} |S_{hh}|^2 + 2(S_{hh} S_{vv}^*) + |S_{vv}|^2 & |S_{hh}|^2 - 2(S_{hh} S_{vv}^*) - |S_{vv}|^2 & 2S_{hh} S_{hv}^* + 2S_{vv} S_{hv}^* \\ |S_{hh}|^2 + 2(S_{hh} S_{vv}^*) - |S_{vv}|^2 & |S_{hh}|^2 - 2(S_{hh} S_{vv}^*) + |S_{vv}|^2 & 2S_{hh} S_{hv}^* - 2S_{vv} S_{hv}^* \\ 2S_{hv} S_{hh}^* + 2S_{hv} S_{vv}^* & 2S_{hv} S_{hh}^* - 2S_{hv} S_{vv}^* & 4|S_{hv}|^2 \end{bmatrix} .....(10)$$

The empirical formula used by the Technical Committee of Canada Centre for remote sensing for coherency matrix is represented in equation (10) [15]. The same formula has been used in the evaluation of the coherency matrix in python system model. The color space aspect of the image data has the consideration for the execution of the formula used.

Here basically $S_{hh}$ is represented for red color. $S_{hv}$ is represented for green color and $S_{vv}$ is represented for blue color [3].

## V. DISCUSSIONS

The image characterization is basically obtained by polarization state of the electromagnetic wave. The various scattering mechanisms obtained through natural distributed targets basically depend on wavelength, dielectric constant and polarization of the EM wave.

TABLE I. PARAMETERS OF ENTROPY BASED TARGET IDENTIFICATION

| Decomposition Method | Feature Parameters | | |
|---|---|---|---|
| | H Entropy | A Anisotropy | α Mean Scattering Angle |
| Entropy based target identification | H=0 only one Eigen value<br>one scattering process surface scattering | Relative scattering<br>Two Eigen values | α=0° surface scattering<br>α=45° dipole scattering<br>α=90° double bounce scattering |
| | H=1 Three equal Eigen values<br>Three scattering process | | |

The mathematical modeling of the target identification is carried by coherency matrix. Identifying the target vector and evaluation of the target vector for entropy based target identification is the major contribution of this paper.

The parameter entropy is the measurement of random feature of scattering process. The degree of randomness of scattering is defined as entropy. Entropy is normally in the range of 0 to unity. It is the logarithmic sum of eigenvalues of coherency matrix.

Anisotropy is the parameter to enhance the quality of the entropy. It gives the relation between scattering which is basically expressed in terms of second and third Eigen values.

TABLE I depicts the parameters of entropy based target identification. The information in the table reflects the scattering property of the target distributed on the earth surface. The backscattering information helps in identifying the target. SAR image is basically combination of energy present for individual image pixel. It depicts the combination of three images. The interpretation of polarization state change of the backscatter is obtained by target vector of the entropy based target identification.

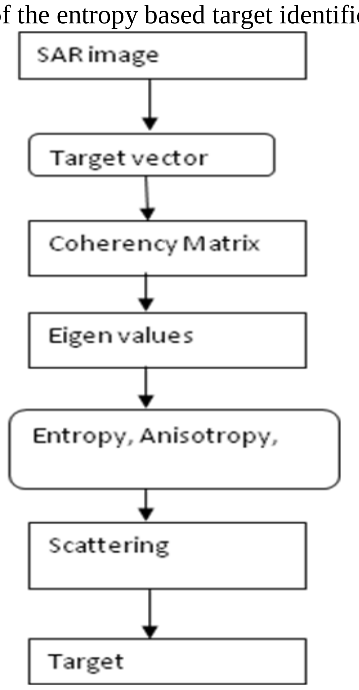


**Fig. 1** Entropy based target identification method

Fig. 1 represents the entropy based target identification method adopted for coherency matrix of SAR image. The scattering properties are characterized by scattering matrix. The elements represent the combination of transmit and receive polarization states.

The coherency matrix and its Eigen values are evaluated through image analysis using Python system model. The Entropy values had range between 0 and unity. The Anisotropy values were between -0.5 to 4.7.

TABLE II. CLASSIFICATION OF ENTROPY

| Parameter | Area | | |
|---|---|---|---|
| | Zone1 | Zone 2 | Zone3 |
| Entropy | Low<br>H=0 to 0.3<br>Surface scattering | Medium<br>H=0.3 to 0.7<br>Double bounce Scattering<br>Secondary scattering | High<br>H=0.7 to 1<br>Multiple scattering<br>Single scattering from volume scattering |

TABLE II depicts the inference drawn from the obtained data.

The data analysis is carried out for set of three different values of entropy.

Accordingly value has been represented for Low, Medium and High kind of entropy. These three ranges of entropy values do represent three different areas. The characteristic of these areas depicts various scattering mechanisms involved by the target. The high value of entropy basically depicts multiple scattering by volumetric information. The low value of entropy represents the surface scattering mechanism by the single surface. The medium entropy values depicts double bounce scattering. The single bounce scattering basically keeps the direction of polarization orientation same. The double bounce scattering represents a kind of definite scattering. The volume scattering is combination of various behavior of scattering. The value of 0 degree for alpha angle specifies the surface scattering. The values 45° and 90° are referred for dipole and double bounce scattering.

The two basic polarization featured vectors $k_C$ and $k_P$ are used in most of the decomposition theory related to SAR polarimetry data. The various types of matrices are developed to represent the scattering behavior of the target.

The various matrices are covariance matrix, coherency matrix, Stokes matrix, Mueller Matrix.

The covariance matrix is formed by the multiplication of lexicographic description and its transpose where as coherency matrix is formed by Pauli based description and its transpose.

## VI. CONCLUSIONS

This paper gives basic ideas regarding the scattering target vector which are helpful for decomposition models. The importance of covariance and coherency matrices are described. The coherency matrix is highlighted and evaluated by the coherency target vector. The effect of scattering mechanism is analyzed by the parameter entropy. System model for entropy based target identification is developed. The involvement of Eigen decomposition techniques for SAR polarimetry is realized. The target vector depicts the scattering property of the backscattering nature of the distributed targets.

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