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Scattering power decomposition-based analysis for target identification

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Abstract

Reflection and non reflection symmetry conditions can be fitted in the scattering models to optimize the coherence power estimation. The SAR formed from received wave is in the form of images which captures the physical feature of the target under consideration. To cohersely extract the target characters prominently the co polarization parameters are considered in the design model. In this investigation a new modified approach with the co polarization parameters is developed. The scattering component and the associated power components computed from the design model illustrate quantitatively a better confidence in evaluating the target. The components namely surface power component, volume power components and double bounce power components are obtained from the scattering parameters. The formulated algorithms model used in decomposition technique gives positive scattering powers. The technique is applied on C band RADARSAT2 images and simulated using a system level mathematical model.

Keywords: Target decomposition; Target characterization; Polarimetry; Scattering mechanism; Scattering power

1. Introduction

The role of synthetic aperture radar in remote sensing has become prime importance in advanced technology. The target to be detected is classified in two categories. They are known to be pure target and distributed target. Pure targets are the manmade structures. The natural objects are called as distributed targets such as forest, snow land, water and vegetation. To retrieve the physical details of the target area the polarimetric decomposition methods are developed. The two basic classification of the decomposition are incoherent target decomposition and coherent target decomposition. The coherent decomposition identifies or models the pure targets. It retrieves the information of pure or coherent targets. The second method known as incoherent decomposition retrieves the information related to the distributed targets. Distributed targets render the complex scattering response because of the speckle noise involved. Speckle noise is the effect of returns obtained through the multiple scattering. This is considered as unwanted effect.

The decomposition models are essential to interpret the scattering mechanism and object identification of the target [1, 6]. So several decomposition models are developed. The decomposition method known as Freeman and Durden decomposition falls under the category of unsupervised classification. This method also represents the incoherent decomposition method. In this method the author assumes target reflection symmetry concept of scattering matrix. The reflection symmetry co relates the off diagonal elements to be equal. $< S_{HH}S_{HV}* >$, $< S_{VV}S_{VH}* >$ to be equal to zero [15]. The model developed by the author describes the responses of the natural targets. The model is known to be three component scattering model due to the three types of scattering mechanism involved in the target. The scattering feature reflects the nature of the object. The three component modeling for power analysis for decomposition is related to PolSAR image by the author. The study is based on the backscatter components from the targets. The model fits the mechanism aspects to the polarimetric SAR data.

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The author Yamaguchi [2] has proposed four component model based decomposition method. The author modeled vegetation canopy for the decomposition analysis. $< S_{HH}S_{HV}* >$, $< S_{VV}S_{HV}* >$ is not equal to zero. The helix scattering is taken as fourth component along with other three types of scattering related to target. The analysis applies to the structures which are complex in nature. In this category structure like urban areas are taken for consideration. This mainly holds man made structure as target under observation.

The author Anupkumar Das describes the biomass related information of the forest in the research paper [3, 5]. The forest growth and deforestation aspect was considered for the SAR application. The effect of radar signal on forest area is described. The information of various bands of operation is explained. The canopy structure contributes for volume scattering. This indicates that the decomposition methods always reflect the physical properties as well as geometrical descriptions of the target.

The authors Quarzeddine and et. al. have illustrated the scattering mechanism related to SAR images [12]. The objectives of the decomposition methods are discussed. The non coherent decomposition methods are analyzed by the author. The entropy evaluation through coherency matrix is discussed along with the elements of Pauli vector represent odd bounce scattering, double bounce and volume scattering components. The resolution cell depicts the average of the scattering mechanisms involved in the SAR images.

The author explains polarimetric interferometric SAR data analysis for forest parameters [8]. The combination of two methods relating model based decomposition and volume scattering was the prime concern.

The author Arrigada [13] describes the decomposition methods based on the scattering matrix related to SAR. The color components are mapped with co and cross polarization components. The analysis depicted the two basic methods of decomposition known as Linear and Pauli decomposition. The mathematical model presented for related decomposition techniques are based on color space model mapping. The computation of decomposition perceived the human sense of color factor. In Krogager decomposition technique the scattering matrix is mapped to coherent components. The components are based on rotation angle.

The authors Mauriozio and et. al. explain the decomposition method applied to the soil structure [14]. The soil moisture is the one of the important factor of analysis. Arri approach to model the volume component related to scattering is also emphasized. The analysis best fits the scattering involved in the canopy structure to the degree of randomness coefficient and orientation angles. The degree of randomness basically depends on various distributions such as uniform distribution, cosine squared distribution and delta function distribution.

The authors represent the various decomposition methods through SVM classification method [4]. The SAR signal mainly depends on the structure of the canopy or vegetation. Its sensitivity of SAR signal includes various parts such as moisture level in leaves, trunk, size and orientation. These features depict the forest density mapping.

The SAR image interpretation is very important aspect in signal processing analysis [7, 11]. The microwave energy signal back scattered from the target area is represented in the form of intensity of pixel. The intensity of each pixel represents the relative proportion of microwave back scattered from that area on the ground which depends on a several factors. These include physical properties like types, size, shape and orientation of the scatterers in the object area. It also includes the moisture content of the target area which is nothing but the nature of the target. The dependency also relates signals technical properties. So it depends on frequency, polarization of signal pulse as well as incident angles of the radar beam.

This paper describes the scattering mechanisms of target in section 2. The section 3 details about the target vector parameters and significance of decomposition techniques. The section 4 explains results. The section 5 explains discussion following section 6 with conclusion.

2. Scattering mechanisms of the target

To extract the information about target as forest, several approaches are in demand. The first method is normalized radar cross section and biomass. The second method is the SAR interferometric analysis. Third approach being the PolSAR or PolInSAR methods depends on the polarimetric parameters. The fourth approach is relating between image texture and biomass. The canopy layer scatterers more information when the C band or X band wavelength is incident on the target [16].

The object is continuously beamed with the electromagneticenergy of the radar signal. The echo obtained from the target basically depends on the nature of the target. The energy signalreflected depends on the scattering feature involved in the object. The scattering mechanism involved in the two targets namely snow and forest are represented. The measurement parameter such as back scatter coefficient is “High” for Dry snowand “Low” for wet snow [9, 10]. The pixel intensity value conversionto physical quantity is called back scattering coefficient.

2.1. Scattering mechanism features in Snow

When we consider the snow as target, there are some important features to be taken care during the observation of the data. Target such as snow are considered under surface scattering object. There will be single reflection from the snow when incident wave fall on the surface. The density of the snow also matters in the reflection of signal. The moisture content in the snow varies from top to the bottom layers ofthe snow. There are two types of snow namely wet type snow and dry type snow. The wet snow exhibits surface scattering. This is because it involves the air and snow interface. The dry snow exhibits the volume scattering for the snow pack. The snow and ground surface exhibits the surface scattering.

2.2. Scattering mechanism in Forest

The target like forest when considered contributes for several scattering mechanisms. It has all three types of scattering mechanisms. They are known to be surface, double bounce and volume scattering. The leaves and tree branches of the tree structure contributes volume scattering. The interaction between ground and tree trunk gives double bounce scattering. The ground below tree structure gives surface scattering. The top layer of the leaves also contributes for surface scattering.

The scattering mechanisms are analyzed through various decomposition methods. According to author Freeman and Durden the three component scattering power decomposition analysis relates the existence of various scattering of the target. The total received power is mapped to sum of thesurface, double bounce and volume scattering mechanisms.

$$P = |SHH|^2 + 2|SHV|^2 + |SVV|^2 = P s + P d + Pv$$

The mathematical representation is given by equation (1). The term P_s indicates the surface scattering power. The P_d and P_v indicates the double bounce and volume scattering power involved.

$$< |SHH|^2 >= |b|^2 f s + |a|^2 f d + f v$$

$$< | SHV|^2 >= \frac{fv}{3} (2)$$

$$< |SVV|^2 >= f s + f d + f v$$

$$< |SHH\, SVV|^* >= bfs + afd + \frac{f_v}{3}$$

The relation between scattering contribution and scattering matrix are represented by equation (2). Here f_s, f_d and f_v are considered to be surface, double bounce and volume scattering mechanism contributions. The variables “a” and “b”are unknown parameters and depends on the S_{HH} and S_{VV} component. The relation between Power component related toscattering mechanism and scattering contributions are related by empirical formula. This is represented by set of equationsas in equation (3).

$$Ps = fs + (1 + |b|^2)$$

$$Pd = fd + (1 + |a|^2)\ (3)$$

$$Pv = \frac{8f_v}{3}$$

3. Target vector analysis and decomposition

The polarimetric data identifies the scatterers in different classification of scattering mechanism based on the decomposition theorem. These methods focus mainly on the identification and properties of scattering mechanism. The target vector represents the fully polarized waves. In case of fully polarized wave with respect to back scattered co ordinate system and associated back scatter alignment the Sinclair matrix is quad polarization in feature.

The Sinclair matrix is converted to the target vector k_c using

$$k_c = \begin{bmatrix} S_{hh} \\ \sqrt{2}\, S_{hv} \\ S_{vv} \end{bmatrix}$$

This target vector mathematical model takes into consideration the penetration depth and back scattering mechanism also.

Another target vector representation in terms of parameter k_p is defined which takes into the account the trace of product of two matrices S and Ψ. Ψ is the representation of Pauli matrices.

The target vector k_p is now defined as

$$k_p = 1/\sqrt{2} \begin{bmatrix} S_{hh+} S_{vv} \\ S_{hh-} S_{vv} \\ 2S_{hv} \end{bmatrix}$$

In the SAR polarimetry principle energy representation of scattering is represented by coherency matrix "C" and covariance matrix "T". C is given by the product of $K_c.K_c^{*T}$ and covariance matrix is given by $K_p.K_p^{*T}$

The target vector can be used to evaluate the covariance matrix and coherency matrices.

In decomposition techniques certain analysis is carried by various researchers. The two scattering components surface scattering and double bounce scattering fall under category of definite scattering.

The volume scattering does not follow the definite scattering. The decomposition methods are essential to know about the targets scattering mechanism feature. The methods depict the involvement of the target. Both these feature identification and scattering are basic conceptual parameters of the decomposition methods.

The decomposition methods are classified into two categories. Coherent decomposition and incoherent decomposition. Normally coherency indicates the involvement of single sample scatterer. Single target basically produces full polarized wave. In coherent decomposition the scattering matrix is subdivided by various sub matrices representing the individual component details. The physical meaning of these components represents the scattering involved by the object. The scattering mechanisms involved are surface scattering, double bounce scattering and volume scattering. The three decomposition methods which are known to be Pauli decomposition, Krogager decomposition and Cameron decomposition are categorized in this method of classification.

The incoherent decomposition method does not hold the certain ground truth measurements. The ground truth measurements include incidence angle, orientation, amplitude and range. In non coherent decomposition techniques the models development focus more on the image characteristics. Dependency of the nature of the object is based on its reflection characteristics. This is known as back scattering.

These models developed under non coherent mechanism specifically take into consideration the co polarization and cross polarization components. These help in the estimation of the scattering type to be mapped to the target object. The methods like Eigen vector, Freeman and Durden decomposition, Yamaguchi4 decomposition, Van Zyl, Huynen, Cloude fall into this category of classification.

The another aspect of consideration is about the matrix analysis carried out in the SAR data representation. The incoherent decomposition follows the step of mapping of scattering matrix into coherency matrix representation. The coherency matrix basically depicts the mechanism of scattering involved. It represent the information regarding the various scattering involved. The elements represented in the diagonal path of the matrix contribute for the total power of the back scattering components. The elements of the matrix help in deriving the various decomposition methods.

The next parameter of consideration is depolarization from the target. Most of the incoherent targets are part of depolarization activity. The coherent target does not have the depolarization of the incident wave. The targets representing coherent back scattering are termed as coherent targets. The incoherent targets tend to show the incoherent back scattering. The vector representation for these targets is one of the prime concerns. Generally Jones vector method is used for back scatter representation of the coherent targets. The mathematical representation adopted for incoherent target back scatter analysis is Stokes vector methods.

The SAR polarimetric decomposition analysis is classified under various techniques of representation. There are two mechanism of approach adopted for standard representation as well as algebraic method of classification. For the coherent targets standard mechanism will follow the Pauli matrices and Krogager's approach. The Cameron approach follows the algebraic method of approach. For incoherent target the approach of standard mechanism is followed by Freeman and Yamaguchi4 decomposition method.

The Eigen vector analysis is method of the algebraic mechanism for incoherent targets. For incoherent target the decomposition method can be analyzed also using polarization state. The Huynen approach basically follows this method of analysis. The representation of scattering matrix to Huynen Euler parameter is one of the contribution by Huynen. Most of the polarimetric analysis is carried out through classification algorithms. The processing of these data are well handled by the digital system based on the algorithms designed. The discussion about this is beyond the scope of this paper.

The decomposition methods signify the characterization of the target. Through the decomposition theorem the polarization data helps to characterize the target. The scattering mechanism and their related properties are accessed by the methods of decomposition. The polarimetric decomposition depends on the scattering element parameters which are part of the Scattering matrix. These basically depict the information regarding the radar target behaviour. This also represents the featured characteristic of the target toward the electromagnetic energy. This is reflection feature of the target. Thus matrix building information is carried out for the pixel representation of the SAR image. Thus the decomposition methods are achieved through the mechanism where in the transformation of scattering matrix is mapped to the vector analysis.

The decomposition method signifies the importance of scattering mechanism. The sum of power component related to scattering mechanism such as surface scattering, double bounce mechanism and volume scattering is related to mechanism involved in the resolution cell.

In SAR polarimetry various decomposition methods are represented to understand the scattering mechanisms involved in the object. These techniques are normally based on some principal approaches. The approaches are known to be Touzi and Chabonneau methods, Huynen methods and non coherent methods. The evaluation of these methods involves dividing the scattering matrices into several elementary scattering matrices. These elementary matrices refer to the particular scattering mechanism of the object. The approach of analysis depends on the two basic basis methods. These are known to be Lexicographic basis and Pauli basis. Both of these basis methods are representation of vector form. The elements of the vector depict the scattering of the object.

The PolSAR scattering power decomposition model depends on physical scattering model. This is normally used in classifying the targets, detection and parameter extraction such as geometrical as well as physical. Such interpretations are carried out by basic and first model known as Freeman and Durden model. The freeman decomposition found to be applicable to the targets like distributed targets. The rough flat surface of the ocean and forests are the best examples of the distributed targets.

The Freeman's methods basically represented the volume scattering mechanism and double bounce scattering mechanism. The objects involved are manmade structure as well as natural objects of the earth surface. Over the years to understand and interpret the scattering in better way the improvement as well as modifications are carried out over this basic model by researchers.

The surface scattering power component P_s, The double bounce scattering power component P_d and volume scattering power component P_v can also be mapped to trace of the relevant coherency matrix. The analysis carried out in this paper depicts the total power evaluation of the sample SAR image as the sum of individual power components of the scattering mechanisms.

4. Results

The model based decomposition methods are helpful in estimating the power components of the scattering involved in the object. This particularly represents the power components of surface, double bounce and the volume scattering. The evaluation of the surface scattering, double bounce scattering, volume scattering components and its power analysis is carried out using the various mathematical equations.

$$P_s = f_s * (1 + |b|^2) \quad (6)$$

$$f_s = \frac{P_s}{1+|b|^2} \quad (7)$$

$$f_s = \frac{|S_{HH}|^2}{1+|S_{HH}-(S_{HH}+S_{VV})/2|^2} \quad (8)$$

$$P_d = f_d * (1 + |a|^2) \quad (9)$$

$$f_d = \frac{P_d}{1+|a|^2} \quad (10)$$

$$f_d = \frac{2 * |S_{HV}|^2}{1 + |(S_{HH} + S_{VV}/2|^2)}$$

$$P_v = \frac{8f_V}{3} \quad (11)$$

$$f_v = 3 * P_V/8$$

$$f_V = 3 * \frac{|S_{VV}|^2}{8} \quad (12)$$

The scattering components are represented by f_s, f_d and f_v.The f_s is known to be surface scattering component. The f_d aref_v are considered as parameter of double bounce and volume scattering component. The scattering components and power scattering components mainly depends on the polarization component of the scattering matrix representation. Theempirical relation between scattering contributions and its power components are analyzed.

The Table 1 represents the results obtained for three scattering components denoted as surface scattering, double bounce scattering and volume scattering for the sample image object as snow image represented in Figure 1. and forest image represented in Figure 2.

Table 1 Scattering Components

Scattering components			
Sample Image	**f_s**	**f_d**	**f_v**
Snow	2.6	19.7	49600
Forest	7.6	4.9	1734

The Table 2 represents the results obtained for power analysis of scattering components involved in the sample image target known to be snow image and forest image.

Table 2 Scattering Power Components

Scattering power Components			
Sample Image	**Ps**	**Pd**	**Pv**
Snow	83 dB	85 dB	66 dB
Forest	92 dB	96 dB	90 dB

5. Discussions

The Synthetic aperture radar data analysis precisely depends on the polarization of the wave. The target vector component inter relates the polarization and scattering mechanisms components. The decomposition method basically depends on the target vector components.

When model based scattering power decomposition is considered, the backscattered power is basically divided among three or four component of representation.

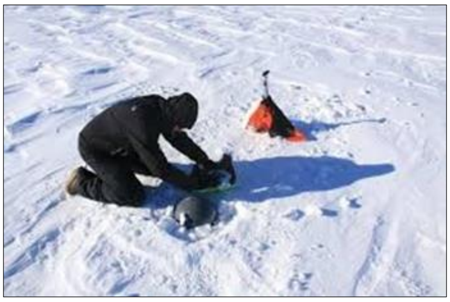

Figure 1 Sample Snow Image

Figure 2 Sample Forest Image

These components involve the scattering power of the object. The number of involvement scattering also allows the decomposition techniques to be named as three or four component model based decomposition techniques.Thus decomposition methods are derived on the basisof types of scattering involved. The information through Polarimetry technique of synthetic aperture radar represents the classification of object through the scattering process.

The decomposition methods like Pauli decompositionmethods are considered, they are accounted as pixel based decomposition methods for target detection as well asclassification. The most of the decomposition theories are based on the feature vectors representation of thedecomposition analysis.

The matrix representation to characterize the scattering property of the target depends on these feature vectors. The power domain parameters are expressed through the feature vector. The several mathematical expressions are also developed to characterize the scattering details. Theseare mainly expressed in power domain through matrices representation.

The model based decomposition methods basically mapsthe scattering matrix elements to model based matrix elements. The total received power estimation is consideredto be the sum of the existing scattering powers in the target.

The mechanism of scattering plays an important role in identifying the features of the object. The analysis presented here describes in detail the mathematical model as well as the target characteristic features. The three main features under discussion are f_s, f_d and f_v.

To evaluate f_s, f_d and f_v components two constants a andb are chosen. The relation between "a" and co polarization elements are expressed as $2a=S_{hh}+S_{vv}$. The value of "a" can be taken into account as

$$a = \frac{S_{hh} + S_{vv}}{2}$$

The value "b" is represented as

$b = S_{hh} - a$

The constants "a" and "b" depend on co polarization value in horizontal direction and vertical direction.

The three components f_s, f_d and f_v are known as surface scattering component, double bounce scattering componentand volume scattering component. Surface scatteringprominently depends on the nature of the target being smooth, rough, uneven or even. The dominance of surface scattering whenever it exist the value of "a" is taken intoaccount.

Discussing the interaction between f_s and P_s, it is observed that the scattering involved in any target mainly depends on scattering power. The surface scattering component f_s ranges in terms of average power. It also takes up the value depending on S_{hh} element of the scattering matrix. For surface scattering strength of the reflection from the object is high since the coverage area is uniform. f_d is directly proportional to double bounce power P_d and inversely proportional to the square of the constant "a". The f_d is double bounce scattering component.

The proposed data analysis of model based decomposition compares the three different scattering mechanism techniques.Here scattering power technique is related to object depending on the nature of the target area. This proposedmethod evaluates the features of snow image and forest images. The scattering involved found to be different for both the images.

The scattering component f_s seems to be low for the snow surface as 2.6 which indicates the scattering power is highly related to this f_s. The entropy for the sample snow image represented in Figure 1. found to be 0.93 and 0.94. Herethe scattering power component P_s, double bounce power component P_d and volume scattering power component P_v found to be in the range of 15,000, 18,000 and 1500.

For sample forest image represented in Figure 2. the parameter f_s, f_d and f_v take up the values 7.6, 4.9 and 1700. This shows there is increase of around 30% increase of allthe scattering components. Entropy found to be 0.7. Thepower component such as surface scattering, double bounce scattering and volume scattering is around 43,000, 70,000 and 34,000. This shows the increase of around 40% as comparedto snow image. 90 dB to 96 dB variation in all three power analysis is observed for forest as the target.

The assumption of reflection symmetry is particularly useful for the natural targets like forest as well as vegetation. This may not be an valid assumption for the targets like urban area objects. These normally involve double bounce scattering from manmade structures.

When we consider the samples like snow and forest some natural observations for the target is done. According to this both of the objects fall under category of dense cluster. This means snow also has layers like structure contributing for its dense structure. For forest it is group of trees and plants contributing for dense structure.

6. Conclusion

The three categories of scattering components namely surface scattering, double bounce scattering and volume scattering are modeled through mathematical concepts. The experimental results support two sample targets to retrievethe target information. The relations between co polarization and decomposition methods are analyzed. The parameters of feature extraction are the three types of scattering power components for sample objects.

The power volume component for forest has increased which indicates the ability to identify the volume power component. The decomposition powers for the target are found to be stable in nature. This indicates that the modified approachadds value for effective decomposition. For forest and snow this technique can be prominently used.

Compliance with ethical standards

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