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UTILISATION OF HYBRID POLARIMETRIC SAR DATA FOR NATURAL RESOURCE MONITORING – A NEW DIMENSION

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ABSTRACT

Natural resource mapping and its monitoring are the key elements for sustainable rural development. Satellite based remote sensing with Synthetic Aperture Radar (SAR) is widely accepted for natural monitoring because of its synoptic view and better temporal coverage due to its unique capabilities to provide day and night measurements, almost independent of atmospheric/climatic conditions. ISRO's Radar Imaging Satellite (RISAT-1) with hybrid polarimetry added a new dimension to explore its utilisation for various applications including natural resource monitoring and further to its management with the inclusion of Geographical Information System. A pilot study has been carried out by considering hybrid polarimetric single look complex SAR datasets acquired over Annaram village in Mahabubnagar district. In the current work, hybrid polarimetric data from RISAT-1 have been analysed and processed for different standard radar targets like corner reflectors and various land cover features using Stokes parameter based decomposition techniques like M-delta, M-chi and M-alpha. The importance of Stokes vector and its derived value added parameter based decompositions are well demonstrated statistically as they aid in characterising target properties based on dominant basic scattering mechanism. Derived Stokes Polarimetric parameters that are decomposed from hybrid polarimetric data are elucidated as the essential basis for better target discrimination and classification. The preliminary results and experience gained in implementation of different emerging hybrid polarimetric decompositions for deriving characteristics of scattering mechanism involved in natural and man-made targets towards sustainable rural development are discussed in this paper.

Keywords: SAR, IDL, RISAT, Polarimetric Analysis Natural Resource Management.

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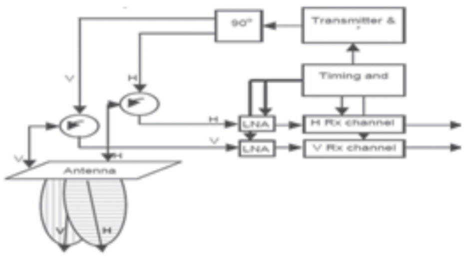
Introduction

For the next few decades, the vision and plan of a developing nation is going to be socio-economic security which will be one of the pillars and the entire space technology would be application-driven instead of technology-driven. The gravity of the present situation is to monitor the natural resources to have sustainable rural development in rapidly developing nations like India and to explore various means and ways in the sphere of remote sensing with geospatial technology towards further development. Usually, during monsoon period (June to October), specifically in India, utilisation of optical remote sensing data is highly hampered by clouds. In this light, microwave remote sensing plays a significant role in supervising the available natural resources, especially during monsoon seasons due to its unique capability to penetrate through the clouds. In Indian scenario, Synthetic Aperture Radar (SAR) data with varying incidence angles, frequency bands, polarisations, resolutions and swath customised for various land, coastal and oceanic applications is expected to enhance the scope of microwave remote sensing primarily for natural resource monitoring and flood mapping during monsoon season.

Over past many years, SAR has received considerable attention for exploiting many applications due to its distinctive capabilities to provide day and night and all-weather imaging system. With recent advances in polarimetry (Boerner W.M, 1998), SAR with hybrid–polarity architecture (R.K Raney, 2006), transmitting circular polarisation (H±iV) and receiving two orthogonal mutually coherent polarisations, which is an excellent demonstration of compact polarimetry(J.C. Souyris, 2005) (R. Touzi, 2009) leading to reduced downlink data rate, bare minimum sensitivity to cross-talks between the channels(Beckmann, 1968) and simple hardware realisation without any trade-off to the swath and resolution(T.L. Ainsworth, 2007). In view of the above capabilities, there is a high demand to understand and further explore the characteristics of polarimetric SAR data to support many terrestrial and oceanic applications.

In the present work, hybrid polarimetric data from RISAT-1(Tapan Misra, 2013) operating in C-band [launched in 2012 by Indian Space Research Organisation] have been analysed for standard targets and various land cover features using Stokes parameter(G.G. Stokes, 1852) based polarimetric decomposition techniques to meet the following objectives: a) Comparative performance analysis of hybrid-polarimetric data based decomposition techniques (m-d, m-? and m-a) for various terrestrial features. b) Sensitivity analysis of polarimetric Stokes parameters for various types of standard targets like corner reflectors of different dimensions. The hybrid polarimetry architecture and capabilities of RISAT-1 SAR sensor is given in Figure 1.



Imaging Mode	Resolution	Swath	Polarisation
Fine Resolution SAR (FRS-1)	3m	25 km	Single, Dual, Hybrid
Medium Resolution SAR (MRS)	25m	115km	Single, Dual, Hybrid
Course Resolution SAR (CRS)	50m	223km	Single, Dual, Hybrid
Fine Resolution SAR (FRS-2)	9m	25km	Quad pol
High Resolution SAR (HRS)	1m	10km	Single, Dual, Hybrid

Figure 1: Hardware Realisation of Hybrid Polarimetry and Imaging Modes of RISAT-1

Study Area, Datasets

Five RISAT-1 Fine Resolution Stripmap (FRS-1) data acquisitions were planned in hybrid polarimetric mode acquired over Annaram village, Mahabubnagar district, Telangana and its environs including Shadnagar has been considered in the present study.

Table1: Details of Study Area and Datasets

S. No.	Date of pass	Imaging orbit	Node	Look	Incidence angle	Area of interest
1	02-11-2013	8379	Ascending	Left	43.510	Annaram village
2	16-01-2014	9510	Ascending	Left	44.120	Annaram village
3	02-05-2016	22132	Ascending	Left	49.8980	Annaram village
4	07-05-2016	22207	Ascending	Right	42.1560	Shadnagar
5	28-05-2016	22524	Ascending	Left	36.0390	Annaram village

The Single Look Complex (SLC) data are obtained as level-1 Geo-tagged product in CEOS format are considered to derive Stokes vectors and Stokes parameters to generate polarimetric decomposed images. The detailed scene information of data are provided in Table 1.

Methodology

The description of the implemented methodology to generate Stokes' vector and Stokes parameters are discussed in this section. Various hybrid polarimetric decomposed images were generated using an in-house software developed in Interactive Data Language (IDL).

Generation of Stokes vector: Any monochromatic EM field can be represented as Stokes' vectors (S_0, S_1, S_2 and S_3) which is adequate to characterise the magnitude and relative phase of a circularly polarised wave. The four Stokes parameters of the backscattered field are represented in Eq[1] in matrix form as

$$\begin{bmatrix} S_0 \\ S_1 \\ S_2 \\ S_3 \end{bmatrix} = \begin{bmatrix} \left\langle E_{RH} |^2 + | E_{RV} |^2 \right\rangle \\ \left\langle | E_{RH} |^2 - | E_{RV} |^2 \right\rangle \\ 2\,\mathrm{Re}\left\langle E_{rh} E_{RV}^{*} \right\rangle \\ -2lm\left\langle E_{RH} E_{RV}^{*} \right\rangle \end{bmatrix} \quad [1]$$

In each case, ERH /ERV represents complex voltage received by the channel with right-circular transmit and horizontal/vertical receive, * represents complex conjugate, < …> denotes ensemble average in time domain; Re and Im represents the real and imaginary value, respectively. Speckle noise is removed by applying convolution filter of 5 x 5 kernel size, as most of the targets in SAR remote sensing require a multivariate statistical description, due to the mixture of coherent speckle noise and random vector scattering effects.

Generation of Stokes Parameters

In response to left/right circularly polarised transmitted signal, it provides Stokes parameters by using data received in two mutually orthogonal channels. Based on the derived Stokes parameters, several useful quantitative derivatives equation [2] to [5] are extracted like, Degree of Polarisation (DoP) (m, representative of polarised and diffused scattering), Circular Polarisation Ratio (CPR, representative of scattering associated with dihedral reflection) and relative phase (δ) between the two linear E-vectors of the backscattered field (an indicator of double bounce scattering).The polarisation state of an electromagnetic wave can be mainly characterised by the DoP, elipticity and relative phase expressed in terms of Stokes parameters.

Degree of Polarisation (m): Degree of polarisation varies from 0 to 1. It is the ratio between polarized power to the total received power of partially polarised wave which is an indicator of polarised and diffused scattering, fundamentally related to entropy.

$$m = \frac{\sqrt{S_1^2 + S_2^2 + S_3^3}}{S_0} \qquad [2]$$

Relative Phase Difference (δ): Its values variy from -180^0 to +180^0 and is well known for single bounce, the backscattered wave is a mirror image of transmitted wave and for double bounce, the backscattered wave is the same as that of transmitted wave.

$$\delta = \tan^{-1}\left(\frac{S_3}{S_2}\right) \qquad [3]$$

Degree of Circularity (χ): It is an unambiguous indicator of even verses odd bounce backscatter, even when the radiated EM field is not perfectly circularly polarised. Ideally, the χ values for single and double bounce are close +45^0 and -45^0, respectively, if RHCP is transmitted.

$$\chi = \frac{1}{2}\sin^{-1}\left(\frac{S_3}{S_0}\right) \qquad [4]$$

Scattering Angle (α): Ideally, 'α' values for single and double bounce are close to 900 and 1000, respectively, if RHCP is transmitted. For 'volume scattering,' 'α' angle is distributed over the range of 22.50 to 67.50.

$$\alpha = \frac{1}{2}\tan^{-1}\left(\frac{\sqrt{S_1^2 + S_2^2}}{-S_3}\right) \qquad [5]$$

Target decomposition theorems identify the different scattering mechanisms which correspond to different sets of theoretical models and further, the analysis of physical scattering mechanisms like surface scattering, double bounce scattering and multiple scattering in relation to the targets that are of user's interest (agriculture, forestry, soil, water body, etc.) using Eq [2] to [5].

Table 2: Scattering Parameters for Different Polarimetric Decompositions

Polarimetric Decomposition	Derivation
m-delta(δ) decomposition	$R = f_{even} = \sqrt{S_0 \times m \times \frac{1-sin\delta}{2}}$ $G = f_{volume} = \sqrt{S_0 \times (1-m)}$ $B = f_{odd} = \sqrt{S_0 \times m \times \frac{1+sin\delta}{2}}$
m-chi (χ) decomposition	$R = f_{even} = \sqrt{S_0 \times m \times \frac{1-sin2\chi}{2}}$ $G = f_{volume} = \sqrt{S_0 \times (1-m)}$ $B = f_{odd} = \sqrt{S_0 \times m \times \frac{1+sin2\chi}{2}}$
m-alpha(α) decomposition 6	$R = f_{even} = \sqrt{S_0 \times m \times \frac{1+cos2\alpha}{2}}$ $G = f_{volume} = \sqrt{S_0 \times (1-m)}$ $B = f_{odd} = \sqrt{S_0 \times m \times \frac{1-cos2\alpha}{2}}$

A novel polarisation decomposition method has been developed (Raney, 2011) and various signal processing techniques have been applied to hybrid polarimetric SAR data so as to map principal components of Stokes parameters through a colour-coded image. By imposing selective filtering, the even/odd bounce and depolarised target signature can be separately mapped into the RGB space where blue indicates single-bounce (and Bragg) backscattering, Red corresponds to double-bounce and Green represents the randomly polarised constituent or volume scattering as expressed in Table 2. Thus, using suitable polarimetric target decomposition techniques (m-delta, m-chi and m-alpha), data can be classified for further monitoring and utilisation of available natural resources.

Results and Discussion

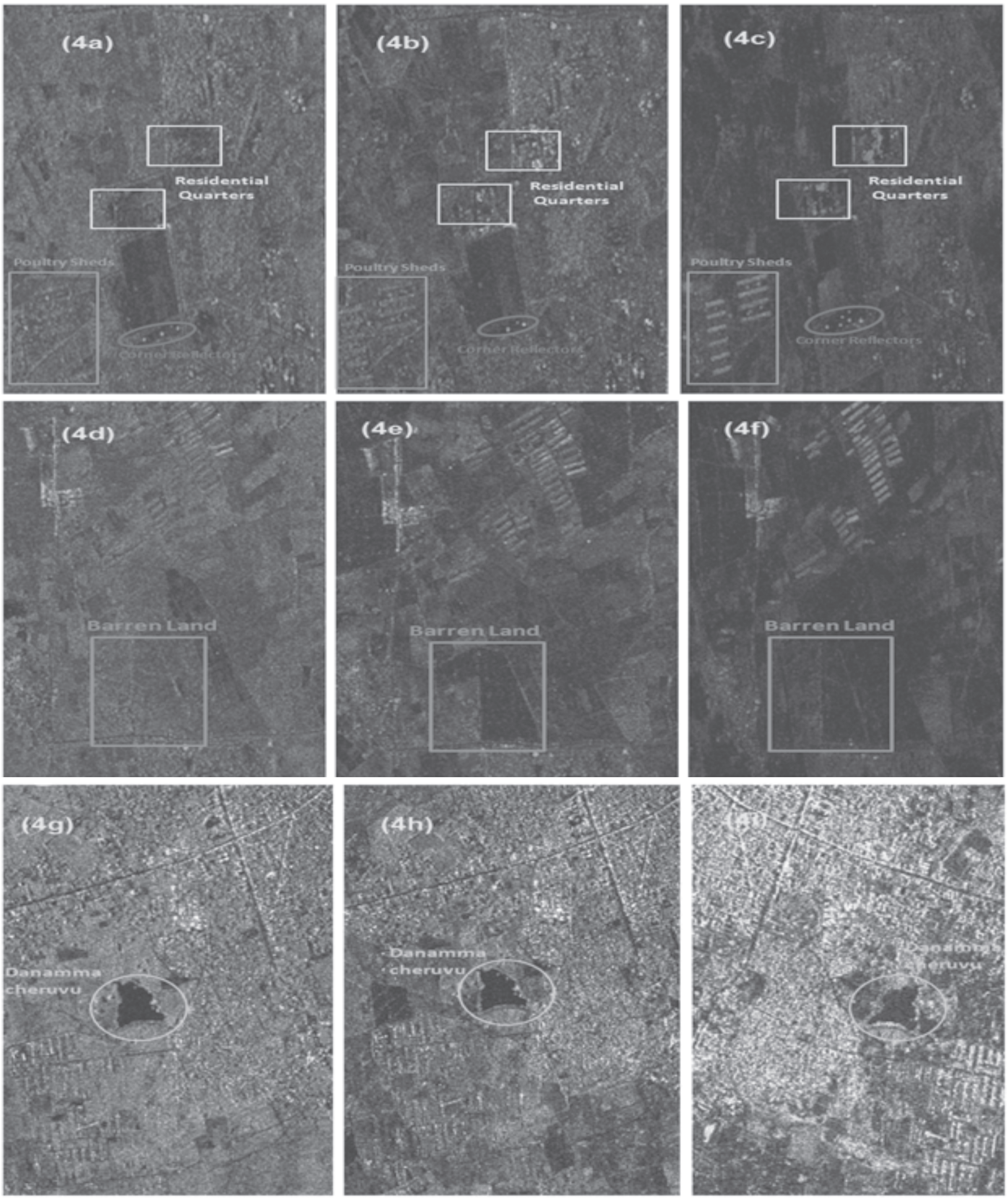
RISAT-1 data acquired over Annaram village and its environs including Shadnagar are considered for implementing polarimetric decompositions, to interpret scattering mechanism over various standard and distributed natural targets where the ground truth is considerably available. Figure 2 shows surface scattering, double bounce and volumetric scattering for various targets using m-delta decomposition.

Figure 2: Representation of M-delta Polarimetric Decomposed Image Along with its Odd, Double Bounce and Volume Scattering Component Images

Yellow circles represent even bounce scattering occurred in Dihedral Corner Reflector and residential quarters characterising double bounce present in di-plane structures. Red and green coloured polygons represent odd bounce and volumetric scattering.

Figure 3: Various Natural and Man-made Features Identified for Polarimetric Analysis Near Annaram Village and its Environs as Visualised in Google Image

Hybrid polarimetric decomposition is applied on various land cover features containing natural and artificial targets which are shown in Figure 4 and corresponding features are identified in google image with relevant ground truth in Figure 3. It can be observed that initially residential quarters and poultry sheds in (4a) and barren land in (4d) are areas with sparse vegetation when data were acquired on 2nd November, 2013 but, later initiated construction activity of quarters and poultry farms (4c) which are well identified as double bounce (yellow boxes) and odd bounce (blue) for the data acquired in 2016.



Date: 2/11/2013 **Date: 16/1/2014** **Date: 7/5/2016**

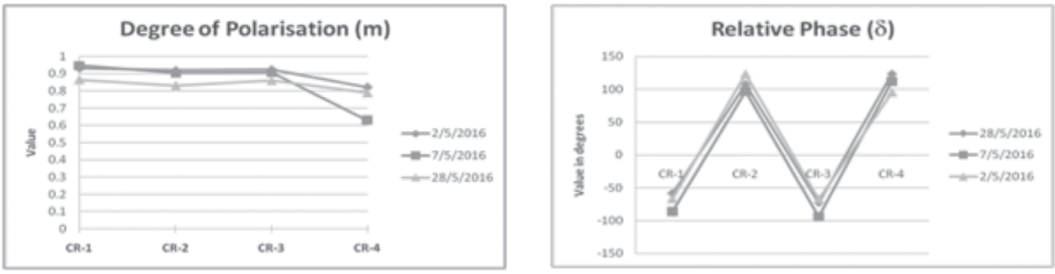
Figure 4: Yellow, Red and Green Representing Even, Odd and Volume Scattering

It is quite interesting to note that barren land with shrubs signifying volume scattering (green) in 4d has been fully cleared (4e and 4f) and modified into residential plots during 2016. However, the water body (4g) near Shadnagar remained unaltered over these three years, except for the increase in built-up area around its surroundings (4i). Table 3 describes the statistical representation of even, odd and volume scattering as derived from m-delta, m-chi and m-alpha decomposition methods implemented on the data. It can be observed that m-delta and m-chi are almost responding in a similar manner for even bounce and odd bounce scattering targets whereas, volumetric scattering is well distinguished in m-alpha decomposition.Therefore, in most of the cases, it is noticed that m-delta supersedes all the other hybrid polarimetric decomposition technique seven in terms of its response from trihedral and dihedral corner reflectors.

Table 3: Statistical Representation of Scattering Mechanisms on Various Targets

Target	M-Delta Decomposition			M-Chi Decomposition			M-Alpha Decomposition		
	Even Bounce (%)	Volume Scattering (%)	Odd bounce (%)	Even Bounce (%)	Volume Scattering (%)	Odd bounce (%)	Even Bounce (%)	Volume Scattering (%)	Odd bounce (%)
Residential Quarters	68.86	23.98	7.15	49.24	20.10	30.66	46.43	31.53	22.04
Dihedral CR	78.25	21.30	0.45	67.81	18.46	13.73	72.44	24.31	3.25
Settlements	41.97	19.56	38.47	41.14	19.55	39.31	48.57	21.79	29.64
Trihedral CR	5.51	22.46	72.03	9.27	21.67	69.06	10.66	25.88	63.46
Poultry shed roofs	3.54	32.30	64.16	17.88	28.44	53.68	0.42	42.34	57.23
Barren Land	22.30	59.50	18.21	22.26	59.48	18.27	15.79	69.59	14.61
Shrubs	39.48	58.71	1.81	32.40	52.89	14.72	17.82	62.33	19.85
Dense Vegetation	30.10	58.97	10.94	27.10	57.44	15.47	20.81	50.93	28.26

The hybrid polarimetric decomposition has been validated for its scattering functionality on standard radar targets called Corner Reflectors (CR), having odd and even bounce behaviour to the electromagnetic wave. A comparative analysis of Stokes polarimetric parameters on these corner reflectors as shown in Figure 5 demonstrate the correctness of implementation of decomposition methodology for land use land cover monitoring.



(a) **(b)**

Figure 5: Plots Representing the Stokes parameters Varaition for Different Date of Passes Corresponding to [a] Degree of Polarisation (m) [b] Relative Phase (δ)

It is observed that Degree of Polarisation is close to 1 as expected for corner reflectors because they have the tendency to preserve the polarisation information based on its structure and its scattering properties.The relative phase is observed to be close to -900 because of double bounce effect which is predominant in dihedral structures and +900 due to odd bounce scattering mechanism persisting in trihedral corner reflector. Slight difference in characteristics of Stokes parameters can be accounted for CR orientation.

Conclusion

In this current work, hybrid polarimetric data of RISAT-1 have been analysed and processed for various land cover features using Stokes parameter based decomposition techniques.The scattering mechanisms derived using decomposition techniques are also validated using standard radar calibration target like corner reflectors.The experience gained in the implementation and analysis of hybrid polarimetric data will help in developing a methodology for classifying natural targets based on various scattering mechanisms.Thus, hybrid polarimetric decompositon methodology will be highly constructive and provides one of the best solutions in monitoring natural resources, periodically leading to sustainable rural development in a structured way, especially during monsoon seasons.The hybrid polarimetric data can be ordered systematically through NRSC data centre. As soon as the data are acquired, it can be processed, decomposed and classified regularly and then related with geo-spatial information to access and monitor sustainable rural development. The potential scope of polarimetric decomposition for target classification can be extended for future national and international space-borne SAR sensors like RISAT-1A, NASA ISRO Synthetic Aperture Radar (NISAR) and Canada's RADARSAT Constellation Mission (RCM), etc., which are also operating in hybrid polarimetry.

References

Stokes G.G. (1852), On the composition and resolution of streams of polarized light from different sources, Trans Cambridge Philos, Soc., 9, 399-416.

J.C. Souyris, P. Imbo, R. Fjortoft, S. Mingot and J.S. Lee (2005), Compact polarimetry based on symmetry properties of geophysical media: the ð/4 mode, *IEEE Transactions on Geoscience and Remote Sensing* Vol.43, No.3, pp.634-646.

T.L. Ainsworth, M. Preiss, N. Stacy, M. Nord and J.S. Lee (2007), "Analysis of compact polarimetric SAR imaging modes," Proc. POLINSAR, ESAESRIN, Frascati, Italy, p7, 22-26 Feb.

Boerner, W-M., H. Mott, E. Luneburg, C. Livingstone and J.S. Paterson (1998), Polarimetry in remote sensing: basic and applied concepts, principles and applications of imaging radar.

Raney R.K. (2011), A perspective on compact polarimetry, *IEEE Geoscience and Remote Sensing, Newsletter,* Vol.160, pp.12-18, sep 2011.

F. Charbonneau ,R. Touzi, Requirements on the calibration of Hybrid –compact SAR, IGARSS 2014, PROC., Quebec, Canada, July 2014.

R. Touzi, "Compact-hybrid versus linear-dual and fully polarimetric SAR", PolInSAR 2009', 26-30 January 2009, Frascati, Italy (ESA SP-668, April 2009).

Tapan Misra, S.S. Rana, N.M. Desai, D.B. Dave, Rajeevjyoti, R.K. Arora, C.V.N. Rao, B.V. Bakori, R. Neelakantan, J.G. Vachchani 2013, *"Current Science",* Vol 104, No.4, Feb 2013.