SAR POLARIMETRIC SIGNATURES FOR URBAN TARGETS - POLARIMETRIC SIGNATURE CALCULATION AND VISUALIZATION

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ABSTRACT:

Various urban targets (land use) from Ahmedabad city were chosen, followed by generation of polarimetric signatures for each target using the developed tool. These polarimetric signatures were then studied and analyzed in detail. An attempt has been to develop a Polarimetric Signature Calculation and Visual Representation Tool assigned name "POLSIC", to generate Co-polarized and Cross polarized signatures, based on the calculation of Stokes Matrix and the backscattered power at various ellipticity and orientation angles. The input parameters required for the developed tool, are the amplitude and phase values of all the four polarizations, for each target using any quadpol radar imagery. In this study, RADARSAT-2 imagery has been used to obtain the amplitude and phase values of each target, in all four polarization states. Polarimetric signatures were generated for various urban targets using the developed tool. Vegetated land, built up in the city, built up within lake, and road were found to have an overall higher polarimetric response (backscattered power) as compared to grass lawn, fallow land and minimum in case of water body. Such Polarimetric responses were obtained due to factors like surface roughness and orientation of the target with respect to the radar look angle. The shape of the signature also indicates the scattering characteristics.

1. INTRODUCTION

A Polarimetric SAR system measures the backscattered energy of the targets in the scene, including its polarization state. The interaction of the transmitted wave with a scattering object transforms its polarization. Polarization signature is a graphical representation of the backscattered power received from a target, as a function of the polarizations of the incident and scattered electromagnetic waves. They show the backscatter response at all combinations of transmit and receive polarizations and are represented as either co-polarized or cross-polarized. Co-polarized signatures have the same transmit and receive polarizations, while the Cross polarized signatures have orthogonal transmit and receive polarizations [6]. In order to study the polarization response of various targets, 'Stokes matrix' has been used. It is a concise description of the polarization response of a backscattering object, given in units of power. It is a 4x4 matrix, an array of real numbers that transforms the Stokes vector of incident wave into Stokes vector of the scattered wave, for a specific target illuminated by a polarimetric radar system. Research interests in this area of polarimetric study of various features have not reached critical mass yet and very few polarimetric processing software tools are available for various polarimetric data types. Most of the softwares available for processing of polarimetric data are either licensed (e.g. SARscape, ENVI), or those that are freeware (e.g. POLSARpro, RAT) do not currently help to calculate and develop the like and cross polarized signatures of various targets based on the stokes matrix. Also, the study and classification of urban targets using polarimetric microwave remote sensing data is still not very widespread as much as in case of optical data. Such a polarimetric study of urban targets, can greatly help in studying the scattering behaviour of various urban features like roads, buildings (tall & short), parks, lakes, open grounds, bridges, agriculture fields (cultivated and non cultivated), etc, thus helping in better land use classification studies using radar data. In the present work, an attempt has been made to develop a Polarimetric Signature calculation and visual representation tool named "POLSIC", to generate both Co-polarized and Cross polarized signatures, based on the calculation of Stokes matrix and the backscattered power at various ellipticity and orientation angles. Various urban targets within a part of Ahmedabad city were chosen, followed by generation of polarimetric signatures (both co-pol and cross pol) for each target using the developed tool. These polarimetric signatures were then studied and analyzed in detail.

2. MATERIAL AND METHODS

2.1 Study Area and Data Used:

For this study, a part of Ahmedabad located at 23° 01'33" N / 72° 27'48" E has been chosen. The city sits on the banks of the River Sabarmati, in north-central Gujarat. It spans an area of 205 km² (79.15 square miles). For this purpose, **C band- RADARSAT-2** data (quadpol, SLC mode), acquired on 18th December, 2009 has been used. In order to verify the targets identified in the RADARSAT-2 data**,** geocoded, VIR, **LISS-4** optical data (resolution: 5.8 meters) was used, with its date of acquisition being 16th November, 2004.

2.2 Development of "Polarimetric Signature Calculation and Visual Representation Tool (POLSIC)":

At this stage of tool development, it allows a new user/researcher ,in the field of polarimetric signature study, to use the tool as a dynamic reference and study material, for viewing ,studying and analyzing the existing class types and their polarimetric signatures, including the stepwise calculations(for both like and cross polarization case).At the same time it could also be used to perform all calculations based on Stokes matrix, by any level of user, save the same and again use them as a reference next time. For a given set of amplitude and phase values, the tool: Calculates Stokes matrix and backscattered power for both Co-polarization and Cross polarization cases; Representation of the same in tabular form on the GUI, with dynamic generation of 3D Polarimetric signatures for both cases; The new values can be saved in the database using the "SAVE "button. User can "EDIT", "UPDATE" and "DELETE" these values from the GUI; For Polarimetric signatures generated, functions like zoom in, zoom out, pan, rotate, data view cursor, colour bar, and legend are provided. The tool is user friendly and easy to learn.

In order to develop the tool, Visual Studio 2005 has been used as a platform, and a Matlab component has been developed to generate 3D plots. The stepwise scientific calculations carried out for developing the tool include input of amplitude and phase values (defined in the GUI), from both, the database, as well as the user. The phase values are converted from degree to radians. This is followed by calculation of real and imaginary parts for the defined amplitude and phase values. Thereafter the expressions of Stokes matrix [K] (Eqn.1) are calculated. Following are the expressions calculated, by taking input from real and imaginary values obtained in the first step.

$$S_{11} = \frac{1}{2}(|S_{hh}|^2 + |S_{hv}|^2 + |S_{vh}|^2 + |S_{vv}|^2)$$
$$S_{12} = \frac{1}{2}(|S_{hh}|^2 - |S_{hv}|^2 + |S_{vh}|^2 + |S_{vv}|^2)$$

$$S_{13} = R(S_{hh}S_{hv}{}^{*} + S_{vh}S_{vv}{}^{*})$$
$$S_{14} = I(S_{hh}S_{hv}{}^{*} + S_{vh}S_{vv}{}^{*})$$
$$S_{21} = \frac{1}{2}(|S_{hh}|^2 + |S_{hv}|^2 + |S_{vh}|^2 - |S_{vv}|^2)$$
$$S_{22} = \frac{1}{2}(|S_{hh}|^2 + |S_{hv}|^2 - |S_{vh}|^2 + |S_{vv}|^2)$$
$$S_{23} = R(S_{hh}S_{hv}{}^{*} - S_{vh}S_{vv}{}^{*})$$
$$S_{24} = I(S_{hh}S_{hv}{}^{*} - S_{vh}S_{vv}{}^{*})$$
$$S_{31} = R(S_{hh}S_{vh}{}^{*} - S_{hv}S_{vv}{}^{*})$$
$$S_{32} = R(S_{hh}S_{vh}{}^{*} - S_{hv}S_{vv}{}^{*})$$
$$S_{33} = R(S_{hh}S_{vv}{}^{*} + S_{hv}S_{vh}{}^{*})$$
$$S_{34} = I(S_{hh}S_{vv}{}^{*} + S_{hv}S_{vh}{}^{*})$$
$$S_{41} = I(S_{hh}S_{hv}{}^{*} + S_{hv}S_{vv}{}^{*})$$
$$S_{42} = I(S_{hh}S_{vh}{}^{*} - S_{hv}S_{vv}{}^{*})$$
$$S_{43} = I(S_{hh}S_{vv}{}^{*} + S_{hv}S_{vh}{}^{*})$$
$$S_{44} = R(S_{hh}S_{vv}{}^{*} - S_{hv}S_{vh}{}^{*})$$

Once these expressions are calculated, it is output on the GUI in the form of unsymmetric Stokes matrix (after normalization).This is followed by calculation of Stokes unit vector (2) for transmitted (T) and received(R) antenna.

$$\vec{S} = \begin{bmatrix} S_0 \\ S_1 \\ S_2 \\ S_3 \end{bmatrix} = \begin{bmatrix} 1 \\ cos\ 2_\chi cos_\emptyset \\ cos\ 2_\chi \sin 2_\emptyset \\ \sin 2_\chi \end{bmatrix}$$

The element S0 is the total power in the wave. The element S1 represents the difference in energy between the two orthogonal components of the wave. The elements S2 and S3 jointly represent the phase difference between the two orthogonal components of the electric field. Backscattered power {P} is then calculated by the expression (3), for both Co-polarization and Cross polarization.

$$\{P_{\emptyset,\chi}\} = \vec{S}_R^T [K] \vec{S}_T$$

In order to compute the Co-polarization and Cross polarization signatures, the above equation is used with values of Ellipticity (X) and Orientation(Ø) angles varying with increments of 5° (-45° to +45° for X and 0° to 180° for Ø). The result is output on the GUI in the form of a table and 3D plot showing backscattered power at various ellipticity (X) and orientation (Ø) angles, for both polarization cases.

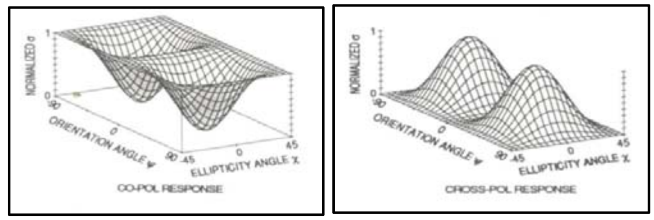


Figure 2.3a: Polarization Response of Dihedral corner reflector obtained "Radar Polarimetry for Geoscience Applications"

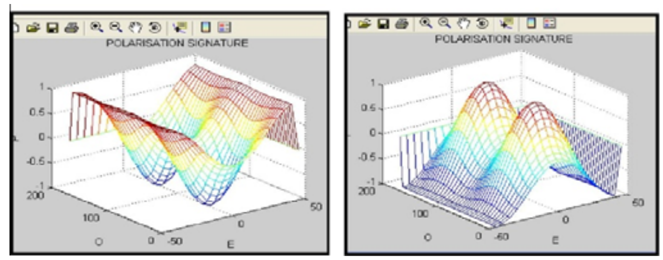


Figure2.3b: Polarization Response of Dihedral corner reflector obtained from developed tool "POLSIC"

From the above figures it is seen that the polarization response of a dihedral corner reflector generated by the developed tool "POLSIC" is similar to that provided in "Radar Polarimetry for Geoscience Applications".The power axis in the developed tool changes dynamically with the zoom level.

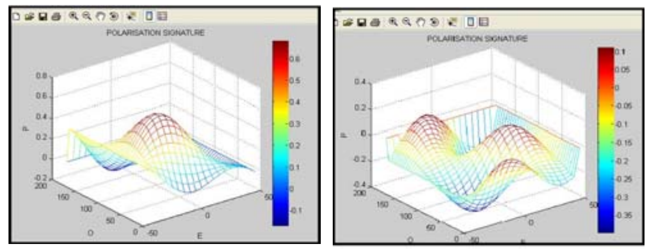
3. RESULTS AND DISCUSSION

The urban classes considered in this study, to carry out the analysis include: Built up (within water body and within city), linear features like roads and bridge, vegetated land, open field, and water body. These targets were identified from the multipolarization RADARSAT-2 imagery, using RAT 0.21 software. The RAT 0.21 software is freeware radar processing software that has the facility to view the geocoded product, and provide information of the real coordinates for various points on the image, along with the amplitude and phase values of a point target in all the four polarization channels (HH, VV, HV, and VH). Using the ground truth data available for the study area, the accuracy check was carried out and it was found that the geocoding done by RAT 0.21software was accurate and the only difference was in the decimal value of the second's part. These targets were then verified using geocoded optical data (LISS-4), on the basis of the real coordinates available. For eah of the target, Polarimetric signatures were generated using the developed tool "POLSIC". From the study and analysis of polarimetric signatures generated for various urban targets, following results were obtained:

3.1 Built up-1, 2 (within city) & Built up within Water body:

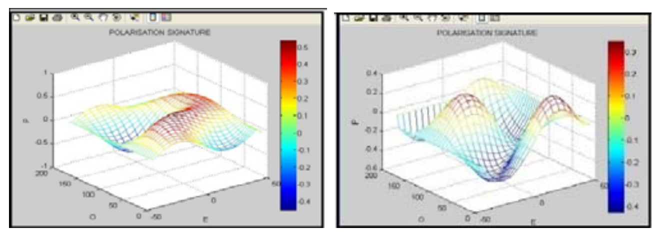
Figures 3.1(a), 3.1(b) and 3.1(c) shows the polarimetric response (copol & cross pol) for three built up targets respectively. These targets have been chosen in three different locations, with different orientations and different surroundings in order to study and analyze their polarimetric responses. The backscattered power values of all the three urban areas appear to be more or less similar. The copolarized response shows that there is a high vertical response with a lower response for horizontally polarized EM waves. The cross polarized response behaves in an exactly opposite manner to the co polarization response. In all the three cases, the cross polarization power response is lower compared to co-polarization power response. For both copol and cross pol responses, there is moderate amount of randomly oriented backscatter that can be viewed from the pedestal heights of each target plot respectively. These built up area responses resemble the polarimetric signature of a dihedral corner reflector with a pedestal component. This is consistent with the fact that an urban area is often composed of buildings, which are essentially dihedral corner reflectors, and trees, which are volume scatterers. However, it is observed that built up-1 and built up within the water body have a higher power response as compared to built up-2. The reason to this difference can be the height of the built up area, orientation of both being perpendicular with respect to the look angle, effect of surrounding buildings, trees, etc.

In case of built up-1, the co-polarized response shows a peak at 0° ellipticity angle and 150° orientation angle, while the cross polarization response shows three maximas at +0° ellipticity angle and orientation angles 0°, 50° and 180° respectively. Built up-2 shows a lower power response, with a peak at 0° ellipticity angle and 135° orientation angle in co-polarization response, while the cross polarization response is reverse, with three peaks, one near +45° ellipticity angle and the other two around 0° ellipticity angle. Built up within the water body, shows a peak at ellipticity greater than 0° and orientation angle around 135°, while the cross pol response shows two minimas around vertical polarization.



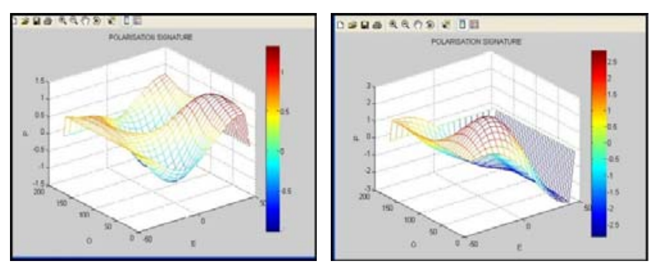
Co-polarized Signature Cross-polarized Signature

Figure 3.1(a): Polarimetric response of Built up-1 (within city)



Co-polarized Signature Cross-polarized Signature

Figure 3.1(b): Polarimetric response of Built up-2 (within city)



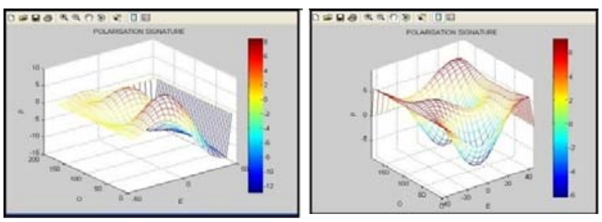
Co-polarized Signature Cross-polarized Signature

Figure 3.1(c): Polarimetric response of Built up within water body

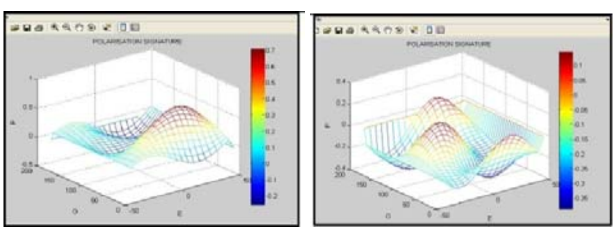
3.2 Road-1, 2 & Bridge (Linear Features):

Figures 3.2(a), 3.2(b) and 3.2(c) shows the polarimetric responses (co-pol & cross pol) of a road-1, road-2 and bridge respectively. In case of road-1, which passes through a built up area in Ahmedabad, it is found that the co-

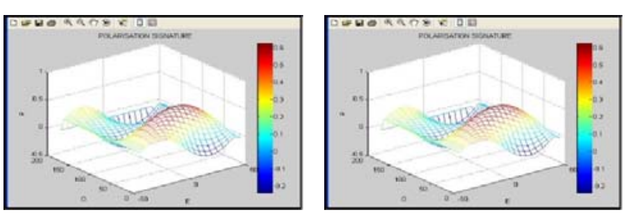
polarization power response is greater than the cross polarization power response. Also the co-polarization response shows higher horizontal response as compared to the vertical response, with two maxima at horizontal polarization.
In case of road-2, which passes through the agricultural fields, in the outskirts of Ahmedabad, the total polarimetric response is less as compared to road-1. There is a single maxima around orientation angle 90° and ellipticity angle +45°. This difference in the polarimetric response of the two roads might be due to the orientation factor, as road-1 is oriented perpendicular with respect to the radar look angle, and since it also passes through the built up area, hence, due to cardinal effect, a strong backscatter signal might be observed, thus giving high backscatter, while in case of road-2, it gives a low polarimetric power response, as it is parallel to the radar look angle. The polarimetric response of road-2 is greatly similar to that of the bridge, indicating similar orientation with respect to look angle.



Co-polarized Signature Cross-polarized Signature
Figure 3.2(a): Polarimetric response of Road-1



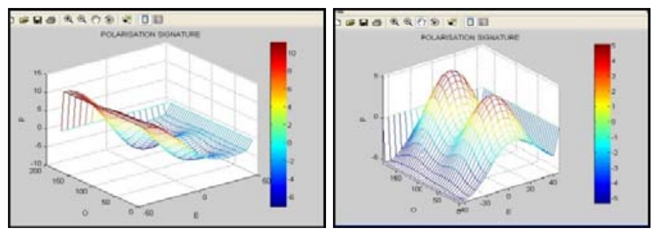
Co-polarized Signature Cross-polarized Signature
Figure 3.2(b): Polarimetric response of Road-2



Co-polarized Signature Cross-polarized Signature
Figure 3.2(c): Polarimetric response of Bridge

3.3 Vegetated Land:

Figure 3.3(a) shows the polarimetric response (co-pol and cross pol) for vegetated land in the outskirts of Ahmedabad City. From the study of its polarimetric signatures, it is seen that the co-polarization backscatter values are greater than the cross polarization power values, and also there is an overall high backscatter. This might be due to the fact that EM waves undergo high multiple scattering on coming in contact with the dense vegetation cover, with majority of volume scattering. The co-polarization signature shows greater response near -50° ellipticity angle, being almost constant at various orientation angles, while the cross polarization signature shows two maxima at horizontal polarization. However both the responses show weak vertical response.

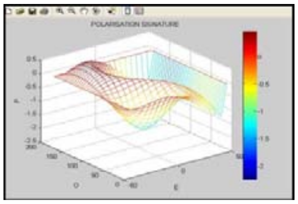


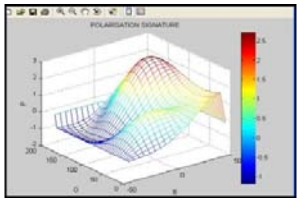
Co-polarized Signature Cross-polarized Signature
Figure 3.3(a): Polarimetric response of Vegetated Land

3.4 Open Field and Water body:

In open field, due to less multiple scattering and greater surface scattering, it causes less backscatter. The cross polarization power response is higher as compared to co-polarization power response, showing the depolarization of the signal.
Figure 3.4(a) shows the polarimetric response (copol and cross pol) of a waterbody (Kankaria Lake) in Ahmedabad city. On analyzing the signatures it is seen that the co-polarization response is less than the cross polarization response. The copol signature shows a higher response at an orientation angle around 180° and ellipticity angle near -45°. Also there is not much variation in the backscattered power response ranging over various ellipticity and orientation angles, indicating less backscatter from the lake. The cross polarization response

appears to be greater near +45° ellipticity angle, indicating higher circular response. Water is an excellent specular reflector, thus leading to greater forward scattering and less backscatter of the EM waves.





Co-polarized Signature Cross-polarized Signature
Figure 3.4(a): Polarimetric response of Waterbody

4. CONCLUSION

In this study, a tool named "POLSIC", with basic capability to calculate and represent 3D Polarimetric signatures (Co-polarized and Cross polarized) has been developed, still in an experimentation phase, in order to encourage and develop Polarimetric signature studies of various possible targets/class. The polarimetric signatures generated for various urban targets, were studied and following conclusions were made: It was found that all the built up structures (buildings, roads and bridge) and the agriculture fields/vegetated areas showed greater Co-polarization response than the Cross polarization response. The open field and water body showed greater Cross polarization response as compared to the above mentioned features. The vegetated land, built up-1(within city), built up within water body, road-1 were found to have an overall higher polarimetric response (backscattered power) as compared to plantation, built up-2, bridge, road-2, open field and minimum in case of water body, due to factors like surface roughness and orientation of the target with respect to the radar look angle. Also rough surfaces like buildings, trees, agricultural fields, etc., cause greater multiple scattering as compared to the smoother surfaces like fallow land, water body, etc. The smoother surfaces (water body, open field) have lower backscattered power values. The minimum intensity indicates the pedestal height of the polarization signature. The rougher surfaces have more multiple scattering and therefore higher pedestal heights than the smoother surfaces. Thus, the shape of the signature also indicates the scattering characteristics. In case of built up areas, roads and bridge, it is found that the predominant polarization intensity differs with the height, shape and the alignment direction of the former, thus giving differences in the polarimetric responses of each.

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