POLARIMETRIC ENHANCEMENT OF POL-SAR IMAGERY APPLIED TO JPL-AIRSAR POLARIMETRIC IMAGE DATA

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Introduction

Radar polarimetry, i.e., the full utilization of electromagnetic vector wave information, has become an indispensable tool in modern radar and imaging technology [1-3]. Polarimetric imaging (polarization filtering) has been carried out by many investigators. Boerner's group ([2-9]) developed the polarimetric-filtering principle for both coherent and incoherent cases using the polarization ratio and Stokes vector formulations. The CAL-TECH/ JPL(NASA) group (van Zyl et al. [10-11]) applied the principle based on the Stokes vector formulation to the imaging of polarimetric SAR data acquired at NASA JPL. Touzi et al [12] proposed a filtering technique for SAR images for reducing speckle. Swartz et al. [13] and Boerner et al. [3] solved the problem by using a decision-theoretic covariance matrix approach. Although many other approaches are available for polarization filtering [2], the distinct radar channel formulation [15-19] is used, i.e., either the Matched, the Co- or Cross (X)-polarization channel. This paper applies the principle to SAR imagery for these three possible polarimetric radar channels and compares the resultant imagery. The radar channels considered here are Co-Pol, X-Pol, and Matched-Pol. channels. Co-Pol means that the receiving antenna has the same polarizaiton state as that of the transmitting antenna, the X-Pol channel has the orthogonal polarization state relative to the transmitting antenna, whereas the Matched Pol channel has an antenna whose polarization state is matched to the scattered wave on receiving. Each channel has its own polarimetric characteristics for target imaging, and these channels can be synthesized by the principle of radar polarimetry. First, the channel imagery for the typical polarization state is given. Then, using the formulation of the contrast enhancement factor [3,9,20,21], i.e., the ratio of desired power versus undesired power, as a discriminator between two target classes, polarimetric enhanced images for Co-Pol and X-Pol Channels are shown using the NASA DC-8 AIR SAR data sets (CC0117L, Bonanza Creek, AK). It is found that the Co-Pol and X-Pol channel imagery plays a dominant role in imaging and retrieving detailed information on specific target characteristics [22].

Channel Power Expression

The polarization state or a completely polarized wave can be expressed by a 4 x 1 Stokes vector, which in terms of tilt angle τ and ellipticity angle ϵ is given as [3]

$$\mathbf{g} = [g_0, g_1, g_2, g_3]^T$$
$$\mathbf{g} = [g, g_0 \cos 2\tau \cos 2\epsilon, g_0 \sin 2\tau \cos 2\epsilon, g_0 \sin 2\epsilon]^T \quad (1)$$

where g_0 is the total power carried by the wave. The tilt angle τ and the ellipticity angle ϵ are geometric parameters of an elliptic polarization state and are in the range of $-45° < \epsilon < 45°$, $-90° < \tau < 90°$, respectively. The relation of these parameters and the Stokes vector are illustrated on the Poincare sphere (in Fig. 1).

Now, let's assume that the radar, under consideration here, has three channel modes for operation (as shown in Fig. 2), i.e., Co-Pol, X-Pol, and Matched-Pol channel configurations. If a unit magnitude wave $\mathbf{g}_t$ of eq. (1) is transmitted, the power for each channel is given [2,9,17] in terms of the 4 x 4 Kennaugh backscattering matrix [K] = [0] [M] which is to be distinguished from the Mueller forward propagation matrix [M], with superscript T denotes transpose as

(a)Co-Pol.: $P^c = \frac{1}{2}\, \mathbf{g}_t^T [A] [K] \mathbf{g}_t = \frac{1}{2}\, \mathbf{g}_t^T [K]_c \mathbf{g}_t$ (2)
(b) X-Pol.: $P^x = \frac{1}{2}\, \mathbf{g}_t^T [B] [K] \mathbf{g}_t = \frac{1}{2}\, \mathbf{g}_t^T [K]_x \mathbf{g}_t$ (3)
(c) Mat.-Pol.: $P^m = \frac{1}{2}\, \mathbf{g}_t^T [C] [K] \mathbf{g}_t = \frac{1}{2}\, \mathbf{g}_t^T [K]_m \mathbf{g}_t$ (4)

where [K] is the Kennaugh matrix, and [0], [A], [B], [C] are Kronecker transformation matrices. [17] Both matrices [K] and [M] represent scattering properties of a radar target. It should be noted that the commonly used Mueller matrix [M] pertains to the forward propagation (optical transmission) case, whereas the Kennaugh matrix to the back scattering radar case. For completely polarized waves the elements of [K] are related to the elements of Sinclair scattering matrix [S] as shown in [1-3]. Care should be taken about the sign of these elements in the power calculation.

Imaging by Typical Polarization States

The data set analyzed is a full polarimetric scene of Bonanza

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Creek, AK, USA, which has been acquired with the NASA AIRSAR system (data set no. CC0117L) on March 19, 1988. It consists of a set of 1024 pixel x 750 line data and is stored in an equivalent Mueller matrix form, different from those of (10). Various polarimetric channel images can be obtained based on the above eqns (2), (3), and (4). Here, images only with 45° oriented linearly polarized transmitted wave case are analyzed (in Fig. 3). Actually, the number of calculated images exceeds more than 20, however, it is impossible to illustrate them all. Most of them are omitted to show in order to save space. It is seen that the Matched polarization channel produces the brightest image because the channel receives all the energy of the scattered wave arriving at the radar. The Co-Pol image which corresponds to 45° -45° polarization combination is the second brightest. For the case of X-Pol channel, the image (corresponding to 45° -135° polarized image) is slightly dark. The averaged power ratios in these channels are; Co-Pol = 0.53, X-Pol = 0.47, and Matched Pol = 1.0 in this scene. From inspection of various specific polarimetric images, it is observed that the images are strongly dependent on the polarimetric channel and the transmitting receiving polarization states [21,22].

Polarimetric Contrast Enhancement in Radar Channel

There are many discrete targets in one radar scene as, for example, shown in Fig. 3. Sometimes we need to discern the details of a specific target within a complex featured scene against undesired background images. This leads to a target enhancement technique which is different from the one applied in the previous section. As a discriminator between two classes, the contrast enhancement factor is defined as the ratio of desired power versus undesired power (desired power / undesired power) [2,9] which leads to the following expression for

(a)Co-Pol channel $C_c = P_1^c / P_2^c$ (5)

(b) X-Pol channel $C_x = P_1^x / P_2^x$ (6)

(c) Matched-Pol channel $C_m = P_1^m / P_2^m$ (7)

where $P_1([K]_1)$ represents the Kennaugh matrix for which we wish to maximize the power and $P_2([K]_2)$ is the one to be minimized (as defined in (2) to (4), respectively). Using the formulation of enhancement factors, we examined how the polarimetric contrast is behaving in the image for each radar channel [21,22].

Let's consider the polarimetric contrast enhancement. The problem here is to find a polarization state which optimizes the enhancement factors. The variable is the transmitting polarizaiton state $\mathbf{g}_t$. Most recently it was found that there exist closed form analytical method for solving the optimal polarization state for eq. (6) -(8). Here we still employ a numerical method at the final stage. Therefore, we employed a numerical approach for finding the optimal polarization state from the outset.

The selected area contains a forested area (f) and wet land regions (riverside (r) 0 for which we wish to enhance the river. This is accomplished by maximizing the polarimetric power densities pertaining to the pixel sets of the river side (r) versus minimizing those pertaining to the forest (f). For this purpose, we have selected two small areas (river side and forested area) which may represent typical but different polarimetric reflection characteristics. Averaging the Kennaugh matrices on the selected area (approximately 20 pixels for each region), it is possible to determine the polarimetric response of these two distributed targets. The Kennaugh matrices for these two classes are found to be:

$$[K]_r = \begin{matrix} 2.2331 & 0.2863 & -0.1515 & -0.3907 \\ 0.2863 & 1.2951 & -0.0347 & -0.1403 \\ -0.1515 & -0.0347 & 0.1837 & 0.5307 \\ -0.3907 & -0.1403 & 0.5307 & -0.7543 \end{matrix}$$

$$[K]_f = \begin{matrix} 1.4171 & 0.1391 & 0.0197 & 0.0338 \\ 0.1391 & 1.0785 & 0.1367 & -0.1105 \\ 0.0197 & 0.1367 & 0.3161 & 0.8231 \\ 0.0338 & -0.1105 & 0.8231 & -0.0225 \end{matrix}$$

Polarimetric power density signatures for the X-Pol channel are shown in Fig. 4 with (a) represents the river side and (b) the forest. Also, the corresponding contrast enhancement factor determined according to (7) for three channels are shown in Fig. 5. It should be noted that a polarization state which maximizes/minimizes the radar return for one specific channel is different from the one which maximizes/minimizes the contrast ratio of (7). With these polarization states, the calculated images are illustrated in Fig. 6.

Conclusion

Three polarimetric channel images are illustrated to show how the polarization plays in SAR imagery. Matched channel always produces the brightest image because it receives the maximum received power. The Co-Pol channel provides the second brightest image, and the X-Pol the third. For the contrast enhanced images for three channels, X-Pol and Co-Pol channel provided similar contrast enhancement factor value. From extensive calculations and comparison of different selected sets, we conclude that the Co-Pol and X-Pol contrast enhanced images are almost the same. The matched channel does not provide high contrast because it always receives the total reflected power and the resulting contrast signature is almost flat.

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Fig.1 Poincare Sphere and geometric parameters

Fig.2 Three polarimetric radar channels

Fig.3 Comparison of Polarimetric channel images (45° oriented linearly polarized transmit) (a) Co-Pol, (b) X-Pol, (c) Matched-Pol image

Fig.4 Polarimetric power density signatures X-Pol channel (a) river side, (b) forested area

Fig.5 Contrast enhancement factor (a) Co-Pol, (b) X-Pol, and (c) Matched channel

Fig.,6 Pol. enh. image (a)Co-Pol, (b)X-Pol and (c) Mat.-Pol channel