EVALUATION OF SYSTEM POLARIZATION QUALITY FOR POLARIMETRIC SAR IMAGERY AND TARGET DECOMPOSITION

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Inference on the scattering mechanisms of targets can be substantially improved using polarimetric synthetic aperture radar (PolSAR) observations [1]. Depending on the physical characteristics of the targets, such as constituent, shape and orientation, the incident electromagnetic wave will change its polarization state accordingly upon scattering. The change of the polarization state can be tracked to detect and discriminate the targets on the radar imagery. Therefore, any polarization deviation due to the sensing platform or the intermediate medium will introduce a distorted view of the target scene, and hence needs to be characterized and calibrated. The quality of PolSAR imagery and its polarimetric decompositions depend on the accuracy of calibrated polarimetric observations. Possible polarization distortions include channel imbalance, cross-talk, and/or Faraday rotation at lower frequencies.

Generally, the polarization distortion should be gauged from two perspectives. From the system design point of view, one expects to determine the system requirement for the applications of interest; whereas from the operational point of view, one expects to assure the accuracy requirement for the calibration process. Both views are related aspects of the same fundamental problem and have drawn attention, for example, for wideband antenna analysis [2] and a SIR-C calibration study [3]. Calibration efforts have accompanied the development of PolSAR system since its inception and are well documented in the literature [4-8]. However, there is no generalized model or metric to evaluate the polarization quality and its impact on PolSAR imagery. In this paper, the polarization distortion is assessed in the context of polarimetric SAR imagery analysis and target decomposition.

Typical polarimetric radars transmit and receive a pair of orthogonal polarization states. In practice, distortion exists in the polarization channels, due to gain imbalances, cross-talk between polarization channels, orientation alignment, and/or residual Faraday rotation. The distortion plays a similar role as basis transformation on the target scattering mechanism $\mathbf{S_t}$, as shown in the system equation

$$\mathbf{S_m} = \begin{bmatrix} 1 & \\ & k_r \end{bmatrix} \begin{bmatrix} g_h & \varepsilon_h \\ \varepsilon_v & g_v \end{bmatrix} \begin{bmatrix} \cos\Omega & -\sin\Omega \\ \sin\Omega & \cos\Omega \end{bmatrix} \mathbf{S_t} \begin{bmatrix} \cos\Omega & -\sin\Omega \\ \sin\Omega & \cos\Omega \end{bmatrix} \begin{bmatrix} g_h & \varepsilon_v \\ \varepsilon_h & g_v \end{bmatrix} \begin{bmatrix} 1 & \\ & k_t \end{bmatrix},$$

where $\mathbf{S_m}$ is the measured scattering mechanism, k_t and k_r represent the channel imbalance between H and V polarizations, ε_h and ε_v represent the cross-talk which satisfy $g_h, g_v \in R;\ g_h^2 + |\varepsilon_h|^2 = 1;\ g_v^2 + |\varepsilon_v|^2 = 1$, and Ω is the Faraday rotation angle. These distortions have varying impacts on the imagery for different target types as well as for different polarimetric decomposition techniques. For example, the polarimetric signature of a spherical target will not change its response due to the orientation rotation. On the other hand, the impact of these distortions is application dependent, relying on how the polarimetric signals are used. An application based solely on the cross-polarization signal will be very sensitive to channel cross-talk. To answer the questions on system requirements and calibration accuracy, we present a general framework and metric to connect the various polarization distortions with their impacts on the PolSAR imagery. Normal treatments analyze the measurement errors in each individual channel [2, 9]. An alternate approach is to compute an integrated term over the full polarization space that incorporates co-polar response and cross-polar responses together into a single entity [3]. Typically, these evaluations were conducted over a few standard targets. As the impact is related to specific targets as well as specific polarimetric applications, a valuable metric should be sufficiently simple to "score" the system merit in the most general sense and capable of preserving the polarimetric information at the same time. Preferably the metric is invariant under polarimetric basis transformation. In this paper, we define a generic metric to gauge polarization quality, which preserves the polarimetric information and is invariant to the change of polarization bases.

In terms of the defined metric, the behavior of different polarization artifacts is evaluated for several typical polarimetric decomposition methods. One goal of this study is to determine which distortions are most critical to decomposition approaches and to what extent the system polarization quality must be maintained for given applications. We evaluate our technique by applying predefined distortions to full polarimetric imagery and then assessing the quality of the distorted data. This illustrates a basic method to determine the requirements for polarimetric radar systems and polarimetric data calibration.

REFERENCES

[1] J.-S. Lee, and E. Pottier, *Polarimetric radar imaging from basics to applications*, CRC Press, 2009.

[2] J.M. Ralston, and E.L. Ayers, "Antenna effects on polarimetric imagery in ultra wide synthetic aperture radar," Institute for Defense Analyses, Sept. 2002.

[3] P.C. Dubois, D. Evans, and J. van Zyl, "Approach to derivation of SIR-C science requirements for calibration," *IEEE Trans. Geosci. Remote Sens.*, vol. 30, no. 6, pp. 1145-1149, 1992.

[4] M.W. Whitt, F.T. Ulaby, P. Polatin, and V.V. Liepa, "A general polarimetric radar calibration technique," *IEEE Trans. Antennas Propaga.*, vol. 39, no. 1, pp. 62-67, Jan. 1991.

[5] A. Freeman, "SAR calibration: an overview," *IEEE Trans. Geosci. Remote Sens.*, vol. 30, pp. 1107-1121, Nov. 1992.

[6] K. Sarabandi; L.E. Pierce, M.C. Dobson, F.T. Ulaby, J.M. Stiles, T.C. Chiu, R. De Roo, R. Hartikka, A. Zambetti, and A. Freeman, "Polarimetric calibration of SIR-C using point and distributed targets," *IEEE Trans. Geosci. Remote Sens.*, vol. 33, no. 4, pp. 858-866, Jul. 1995.

[7] A. Luscombe, A. Thompson, K. James, and P. Fox, "Calibration Techniques for the RADARSAT-2 SAR System," *Proc. EUSAR*, 2006.

[8] T.L. Ainsworth, L. Ferro-Famil, and J.-S. Lee, "Orientation angle preserving a posteriori polarimetric SAR calibration," *IEEE Trans. Geosci. Remote Sens.*, vol. 44, no. 4, pp. 994-1003, April 2006.
[9] T. Macklin, P. Wright, and P. Meadows, "Sensitivity of SAR Calibration to the Combined Effects of Cross-Talk, Channel Imbalance and Faraday Rotation," in *Proc. EUSAR*, 2006.