The SSCM for ship characterization using polarimetric SAR

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Abstract— **Ship characterization is investigated using the symmetric scattering characterization method (SSCM), which was introduced in [12]. The SSCM method appears to be very promising for ship identification. Identification of ship targets with significant symmetric scattering is shown to lead to accurate pitch measurement, under certain conditions.**

I. Introduction

Ship detection and identification has many potential applications within the commercial, fishery, vessel traffic services, and military sectors. Future satellite SARs, such as RADARSAT-2 and ALOS-PALSAR, will be fully polarimetric, and as such, provide additional information which will permit better characterization of the illuminated targets. Polarimetric information was investigated in [11] for ship detection at operational satellite SAR incidence angles (20° to 60°). It is shown that fully polarimetric information permits a significant improvement of ship-sea contrast, in comparison with the conventional (scalar) one channel polarization (HH, VV, or HV). In this study, ship identification and characterization are investigated, with reference to ground truth data collected during the acquisition. The symmetric scattering characterization method, SSCM [12], is used for a high-resolution characterization of ship scattering. The potential of the SSCM method for ship identification, and ship pitch measurement, is studied.

II. Optimum polarimetric information extraction for high-resolution applications

Partially coherent target decomposition methods, such as the Huynen and Cloude methods [5], [2], which extract the polarization information from multi-look Mueller, covariance, or coherency matrix are not suitable for applications that require high-resolution data, such as ship identification. Ship identification requires the use of coherent target decomposition methods (CTD), such as the Huynen, Krogager, and Cameron methods [5], [6], [1], which extract the polarization information from the high-resolution 1-look scattering matrix. Cameron's CTD was reconsidered in [12]. This method, which was inspired by the work of Huynen [5], associates importance to a class of targets termed symmetric. A symmetric target as defined in [5] is a target having an axis of symmetry in the plane orthogonal to the radar line of sight direction (LOS). Symmetric targets have a scattering matrix which can be diagonalized by a rigid rotation about the LOS in a basis of linear eigen polarizations. Cameron developed an algorithm that maximizes the symmetrical component of coherent scattering [1], which is then expressed as the sum of independent elements in order to associate a physical mechanism with each component. For operational use of his CTD, Cameron introduced a classification method [1], which has been widely used for characterization and identification of point targets such as ships [9], [15] and small planes [8]. Unfortunately, it was shown in [12] that Cameron's classification yields mis-leading results because of the significant radiometric dispersion that is tolerated (up to ±8 dB), and the absence of criteria that avoids the application of the CTD decomposition method in areas of non-coherent scattering. A new method, named the symmetric scattering characterization method (SSCM), was introduced in [12] to better exploit the information provided by the largest target symmetric scattering component. The SSCM, which expresses the symmetric scattering in terms of the target's Poincaré sphere parameters, permits a high resolution characterization of target symmetric scattering under coherent conditions [12].

III. The SSCM method for characterization of symmetric scattering

A. Maximization of symmetric scattering

Under target and SAR system reciprocity assumptions, the target scattering matrix is expressed in terms of the Pauli matrices as [1]:

$$[S] = \alpha[S_a] + \beta[S_b] + \gamma[S_c] \quad (1)$$

Scattering is symmetric if there exists an angle of rotation ψ_a that cancels the projection of $[S]$ of equation (1) on the non-symmetric Pauli direction $\vec{S}_c$, where $\vec{S}_c$ is the vectorial form of the Pauli matrix $[S_c]$. This leads to the following expression for the symmetric part, $\vec{S}_{sym}$, as a function of the angle $\theta = -2\psi_a$ [1]:

$$\vec{S}_{sym} = \alpha\vec{S}_a + \epsilon \cdot [\cos\theta \cdot \vec{S}_b + \sin\theta \cdot \vec{S}_c] \quad (2)$$

The symmetric component $\vec{S}_{sym}$ of the total scattering $\vec{S}$ (the vector form of $[S]$), reaches its maximum for the

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angle θ that satisfies the following relationship, for $\beta \neq \gamma$ [1]:

$$\tan(2\theta) = \frac{\beta\gamma^* + \beta^*\gamma}{|\beta|^2 - |\gamma|^2} \quad (3)$$

After diagonalization, the largest symmetric component $\vec{S}_{sym}^{max}$ can be expressed in the trihedral-dihedral basis, ($\vec{S}_a$, $\vec{S}_b$), as:

$$\vec{S}_{sym}^{max} = \alpha\vec{S}_a + \epsilon\vec{S}_b \quad (4)$$

where ϵ is given: $\epsilon = (\beta\cos\theta + \gamma\sin\theta)$

B. Poincaré sphere for representation of symmetric scattering

The maximized symmetric component $\vec{S}_{sym}^{max}$ is characterized by the two complex entities α and ϵ of equation (4). After normalization by the total intensity ($|\alpha|^2 + |\epsilon|^2$), each diagonalized symmetric scattering vector $\vec{\Lambda}$ was expressed in [12] as a function of the Target Poincaré Sphere angles ψ_c and χ_c, as:

$$\vec{\Lambda} = \left[\ 1 \quad \cos(2\chi_c)\cos(2\psi_c) \quad \cos(2\chi_c)\sin(2\psi_c) \quad \sin(2\chi_c)\ \right] \quad (5)$$

where ψ_c and χ_c can be derived as a function of the target parameters α and ϵ of equation (4). Each symmetric scatterer can then be represented as a point of latitude $2\psi_c$ and longitude $2\chi_c$ on the target Poincaré unit sphere presented in Figure 1. To remove the rotation phase ambiguity, only half of the sphere is used with ψ_c varying within the interval $[0, \pi/2]$. If ψ_c is lying in the interval $]\pi/2, \pi]$, symmetric scattering sphere coordinates (ψ_c,χ_c) are replaced with ($\pi - \psi_c$,-χ_c), and the rotation angle ψ_a of equation (2) is replaced with $\psi_a \pm \pi/2$.

Only a coherent symmetric scatterer can be represented as a point on the surface of the Poincaré sphere. A partially coherent symmetric scatterer is represented as a point inside the sphere at a distance from the sphere center determined by the degree of coherence, p_{sym}, which was defined in [12]. The parameter p_{sym}, called the degree of symmetric scattering coherence, is used in the following to limit the application of the SSCM within coherent areas.

C. SSCM scheme

The SSCM includes the following steps [12]:
1. Calculation of the parameters α and ϵ of the maximum symmetric component, using Cameron's CTD [1].
2. Classification of distributed target scattering into coherent and non coherent classes using p_{sym} information.
3. Classification of point target scattering into coherent and non-coherent classes using the Rician threshold [12].
4. Computation and analysis of the S_{max} Poincaré sphere parameters within the coherent class.

IV. Ship characterization using the SSCM

In the following, the SSCM is applied for ship characterization using several data sets collected with the Department of the Environment airborne Convair-580 SAR [7], in an experimental trail Crusade'00 [4]. The Crusade'00 trial data were collected off Cape Race, Newfoundland in March, 2000 [4]. During the Crusade'00 trial, ships were almost stationary, and were well ground-truthed [4], [3], [15].

In this study, the polarization information is investigated for the Anne S Pierce (ASP) of Figure 2 with reference to the ground truth data. ASP was imaged in rough sea conditions at 39° (line 1 referred to as L1P3) and 35° (line 6, pass 8 referred to as L6P8) incidence angle with wave height of 4 meters. At the time of acquisition, ASP was oriented with an angle of 8° (L1P3) and 15° (L6P8) with reference to the along-track SAR direction. The mast in the middle and two metallic features in the front and at the back of the ship, referenced to as MID, DF, and DB in Figure 2, are potential targets of symmetric scattering. Table 1 presents the coordinates (ψ_c, χ_c) on the Poincaré sphere of these features. The (MID) antenna ψ_c angle appears stable (within 3°) during the 2 flights with an average scattering close to the dipole scattering angle. The two values of χ_c are about 30° apart. A deeper analysis of the ship responses reveals a severe focus error on the ship in L6P8; ship trace is 50% longer at L6P8 in comparison with L1P3. Focus setting errors introduce a significant error in the peak intensity parameters, and the phase of the peak intensity is more sensitive to focus setting than the intensity, as shown in [10], [14], [13]. This explains the big offset noted in χ_c, which directly relates to the trihedral-dihedral phase difference. In contrast, ψ_c that depends strongly on the channel relative intensity appears to be less affected by the system focus setting errors. Consequently, unless the focus setting errors are removed from the second line, the information provided by the SSCM is not reliable.

TABLE 1: ASP main feature's Poincaré sphere coordinates (ψ_c, χ_c).

Line	MID	DF
L1P3	(53.6°,2.3°)	(49.7°,24.5°)
L6P8	(50.7°,-30.3°)	(25.4°,-7.3°)

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The first data set, which looks well focused, can be used to estimate the ship motion angles at the data acquisition. Since the ship orientation angle is small (15°), the rotation angle ψ_a can be taken as an estimate of the pitch angle. MID and DF rotation angles lead to pitch estimates of $-0.9°$ and $-1.1°$, respectively, as seen in Table 2. This agrees well with the on-broad measurement of -1.0° collected during the acquisition. As expected, the second set which suffers from mis-focussing leads to a an erroneous pitch estimate (cf. Table 2).

TABLE 2: Pitch measurements with reference to ground truth

Line	MID Pitch	DF Pitch	Meas.
L1P3	-0.9°	-1.1°	-1.0
L6P8	-6.0°	-9.4°	0.23°

V. Conclusion

The high resolution SSCM method introduced in [12] looks to be very promising for ship characterization. The ability to identify on the ship elemental targets of significant maximized symmetric scattering component, provides a ship specific distribution of "permanent" scattering targets, which might be useful for ship identification at various wind and sea conditions. Such targets were used here successfully for an accurate estimate of the ASP's pitch angle, for particular wind and sea conditions. However, the SSCM which strongly depends on the signal phase and intensity of the peak signal, remains very sensitive to the system focus setting [10], [14] and Doppler centroid shift [13]. These errors should be removed prior to the application of the SSCM method.

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References

[1] W.L. Cameron, N. Youssef, and L.K. Leung. Simulated polarimetric signatures of primitive geometrical shapes. *IEEE Trans. Geoscience Rem. Sens.*, 34(3):793–803, 1996.

[2] R. Cloude and E. Pottier. A review of target decomposition theorems in radar polarimetry. *IEEE Trans. Geoscience Rem. Sens.*, 34(2):498–518, 1996.

[3] R.K. Hawkins, K.P. Murnaghan, M. Yeremy, and M. Rey. Ship detection using airborne polarimetric SAR. In *CEOS SAR Workshop Proc., Tokyo*, pages 6–15, April 2001.

[4] R.K. Hawkins, W. Wong, and K. Murnaghan. Crusade Experiment March 2000. In *Canada Centre for Remote Sensing CCRS-TN-2000-07*, March, 2000.

[5] J.R. Huynen. Measurement of the target scattering matrix . *Proc. IEEE*, 53(8):936–946, 1965.

[6] E. Krogager. New decomposition of the radar target scattering matrix. *Electronic Letters*, 26(18):1525–1527, 1990.

[7] C. E. Livingstone, A. L. Gray, R. K. Hawkins, P. W. Vachon, T. I. Lukowski, and M. LaLonde. The CCRS airborne SAR systems: Radar for remote sensing research. *Can. J. Rem. Sens.*, 21(4):468–491, 1995.

[8] H. Rais and A. W. Mansfield. L-Band/P-Band SAR Comparison for Search and Rescue: Recent Results . In *Proc. of the SPIE Aerosense Conference*, 5-9 April 1999, Orlando, Florida.

[9] R. Ringrose and N. Harris. Ship detection using polarimetric SAR data. In *Proc. of the CEOS SAR workshop, ESA SP-450, http://www.estec.esa.nl/CONFANNOUN/99b02*, October 1999.

[10] R. Touzi. Extraction of point target response characteristics from complex SAR data. *IEEE Trans. Geoscience Rem. Sens.*, 30:1158–1161, 1992.

[11] R. Touzi. Calibrated polarimetric SAR data for ship detection . In *Proc. 2000 Int. Geosc. Remote Sensing Symp., IGARSS'00* , Honululu, Hawaii, 2000.

[12] R. Touzi and F. Charbonneau. Characterization of target symmetric scattering using polarimetric SARs. *IEEE Trans. Geoscience Rem. Sens.*, 40, Nov., 2002.

[13] R. Touzi and K. Raney. Effect of Doppler centroid mis-tracking on the Parameter estimation of point target complex signals. In *Proc. 1994 Int. Geosc. Remote Sensing Symp., IGARSS'94* , Pasadena, California, 1994.

[14] R. Touzi, K. Raney, and A. Lopes. On the use of complex SAR data for calibration. In *Proc. 1992 Int. Geosc. Remote Sensing Symp., IGARSS'92* , Houston, Texas, 1992.

[15] M. Yeremy, J.W.M. Campbell, K.Mattar, and T. Potter. Ocean surveillance with polarimetric SAR. *Can. J. Rem. Sens.*, 27(4):328–344, 2001.

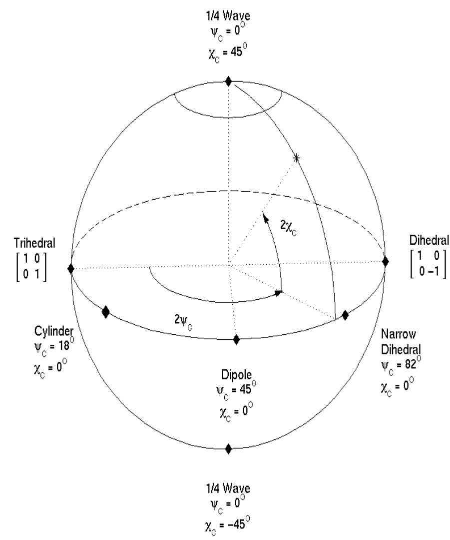

Fig. 1. S_{sym}^{max} *Target Sphere*

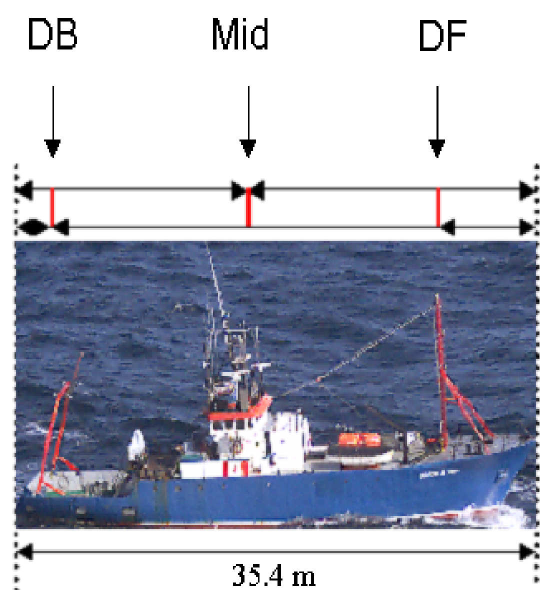

Fig. 2. *Anne S Pierce (ASP)*