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ADVANCED POLARIMETRIC SYNTHETIC APERTURE RADAR (SAR) AND ELECTRO-OPTICAL (EO) DATA FUSION THROUGH UNIFIED COHERENT FORMULATION OF THE SCATTERED EM FIELD

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Abstract—Exploitation of the backscattered field polarization over the wide electromagnetic spectrum, from visible to microwave frequencies, provides an approach to advanced target recognition in remote sensing applications. The framework for full coherent characterization of the scattered field that is established here, maximizes the extracted target information. It is also shown that such a methodology, which is theoretically similar to the concept of "partial or compact polarimetry", yields comparable results to full or quadrature-polarized systems by incorporating judicious assumptions and assuming/implementing optimal transmitted or illumination field polarizations. On this basis, common characteristic features, interworking and fusion of different polarimetric sensor products in different regions of spectrum, e.g., radar/SAR and Electro-Optical, are investigated and formulated within a robust framework based on full coherent treatment of the scattered field.

1. INTRODUCTION

Exploiting polarization characteristics of the backscattered electromagnetic (EM) waveform provides significant insight into the nature of targets, and additional information for target recognition compared to conventional remote sensing sources. This is supported by the well-established physics of EM fields and waves [1–5]. In short, EM polarimetry, from microwave to visible frequencies, provides an enhanced capability for advanced target recognition in remote sensing applications.

The objective here is to explore the interworking and fusion of EM polarimetric observables and measurables associated with certain classes of targets in different regions of the EM spectrum. One prominent example is the combination of Synthetic Aperture Radar (SAR) polarimetry with EM polarimetric sensors in higher frequency bands such as the visible or optical region, e.g., Electro-Optical (EO). Characteristic advantages of such fusion or hybrid approaches can be summarized as follows:

- First and foremost, in theory, target identity established through scattering characteristics will be more uniquely defined in a wider range of the EM spectrum even if the spectrum expansion is incoherent (i.e., incoherent bandwidths). Such spectral diversity provides a more comprehensive nature of scattering and the target.
- Polarimetric backscatter characteristics for a certain target class (or classes) of interest are consistent throughout various regions of the EM spectrum (e.g., polarization selectivity for manmade objects). Therefore, proper fusion of EM polarimetric returns in different bands can, in principle, enhance the contrast of such objects/targets compared to those with low or without the addressed polarization selectivity (e.g., clutter).
- The described EM polarimetric nature (polarization selectivity) manifested in different regions of the spectrum can be effectively exploited for calibration purposes. For instance, specification of the target polarization plane (e.g., the polarization orientation angle) may be extracted thus exploiting data from the sensor in one domain for exploitation and calibration in the other domain. Such interworking is applicable and effective for any polarization-related property associated with target physics that is consistent throughout the EM spectrum (or essentially within the operating bands of interest).

The described fusion of polarimetric data from SAR and other sensors from a different region of the EM spectrum, e.g., electro-optics (EO), should be performed within a robust framework based on careful modeling of the EM wave scattering and characteristic observables. Considering the general property of the scattered EM wave being polychromatic and partially polarized, the analytic polarimetric EM signal is best-characterized by virtue of the Stokes vector and parameters. The scattering phenomenon can also be formulated within the same framework using Mueller, coherency or variance matrices [1, 6–8].

2. ELECTROMAGNETIC (EM) SCATTERING

The identity of objects/targets interacting with the EM field in remote sensing is characterized by virtue of the EM scattering concept. The EM field scattering operator is analogous to the conventional target reflectivity function but provides a broader and more comprehensive picture of scattering. In particular, it contains information on the scattered field polarization that is valuable for target characterization. In any region of the EM spectrum, target scattering can be formulated as:

$$\mathbf{F}_s(\mathbf{x},\omega) = \overleftrightarrow{\mathbf{S}}(\mathbf{x},\omega) \,.\, \mathbf{F}_i(\mathbf{x},\omega) \tag{1}$$

where $\overleftrightarrow{\mathbf{S}}(\mathbf{x},\omega)$ denotes the scattering operator in the space and time-frequency domain, and $\mathbf{F}_i(\mathbf{x},\omega)$, $\mathbf{F}_s(\mathbf{x},\omega)$ represent the incident and scattered fields, respectively. For typical applications, these vector field components represent the electric field, i.e., $\mathbf{E}_i(\mathbf{x},\omega)$ and $\mathbf{E}_s(\mathbf{x},\omega)$. In (1), "." denotes the dot or inner product. As is evident from (1), the identity of a scatterer at position $\mathbf{x}$ is completely and uniquely defined (theoretically) over the whole spectrum. Thus, waveform diversity (for both incident and scattered fields) is required to establish the complete scatterer identity. That is, target recognition will be enhanced through spectrum diversity. In the present formalism, the excitation (i.e., incident field) and receive (i.e., scattered field) points may be in different spatial locations, which is the case for bistatic radars. Also, the incident field source of scattering may not be controlled or coherent.

The general formalism of (1), although simple in conceptual representation, is very involved for practical target recognition applications. The coherent scattering target operator or matrix that contains comprehensive scatterer information may be difficult to relate to target characteristics for practical applications. This is due to many factors such as the noted incomplete spectral content, random effects, partial or non coherence (with respect to the source excitation/incident field) associated with the scattered field or wave. Considering the above, the scattered field or wave analysis becomes a viable choice for scatterer characterization. This EM field analysis approach that is essentially based on scattering vector analysis (rather than the scattering operator or matrix) is similar to the emerging "compact polarimetry" methodology [9–13] that exploits scattering system response to an incomplete set of input EM field components. Although, the unique scattering transfer function is mathematically ill-defined, certain assumptions may be made (e.g., symmetry) to reconstruct the scattering matrix [12].

To extract the most information about the target from its random backscatter response with unknown orientation relative to the known polarity of the radar illumination (i.e., the typical practical scenario), the backscattering measurement potential of SAR should be maximized. The latter is maximized if and only if the data products are the 4 Stokes parameters (or their logical equivalent) [10]. This is in agreement with the statement made earlier based on classical EM physics that the analytic polarimetric EM signal (polychromatic and partially polarized) is best characterized by virtue of the Stokes vector and parameters. The above statement is valid for a polarimetric EM signal throughout the whole spectrum, from the microwave to the visible range.

In this work, the wide-spectrum scattered EM field (partially/completely polarized or coherent) is formulated in a unified manner, and in terms of components/products of significance for scattering analysis. Since these EM observables are characterizing field and scattering in different regions of the spectrum, fusion of various sensors utilizing polarimetric EM remote sensing for advanced exploitation is envisioned.

3. EM FIELD FORMULATION AND OBSERVABLES

3.1. EM Wave Analytic Description

A general *polychromatic* EM wave propagating in the direction $\mathbf{r}$ can be analytically represented by:

$$\boldsymbol{\varepsilon}(\mathbf{r},t)=\mathbf{E}(\mathbf{r},t)\exp\left(j(\omega t-k_0L(\mathbf{r},t))\right) \tag{2}$$

where $\mathbf{E}(\mathbf{r},t)$ is the complex vector field phasor, $k_0=\frac{2\pi}{\lambda}=\frac{\omega}{c}$ and c are the vacuum wavenumber and speed of light with λ being the wavelength, and $\mathbf{r}=(x,y,z)$ denotes the position vector. Providing that the waveform bandwidth is small compared to the center frequency, a *quasi-monochromatic* model can be adopted as:

$$\boldsymbol{\varepsilon}(\mathbf{r},t)=\mathbf{E}(t)\exp\left(j(\omega t-\phi(t))\right) \tag{3}$$

In the spectral domain, the *polychromatic* EM signal (2) can be represented as:

$$\begin{aligned}\tilde{\boldsymbol{\varepsilon}}(\mathbf{r},\omega) &= \tilde{\mathbf{E}}(\mathbf{r},\omega)\exp\left(-j(k_0\tilde{L}(\mathbf{r},\omega))\right)\\ &= \tilde{\mathbf{E}}(\mathbf{r},\omega)\exp\left(-j(k(\mathbf{r},\omega))\right)\end{aligned} \tag{4}$$

The time invariant (or implicit time variant) complex vector EM field/wave in the **EH** plane (i.e., perpendicular to the direction of wave propagation or the Poynting vector) may be expressed as:

$$\mathbf{E}(\mathbf{r}) = E_x(\mathbf{r})\mathbf{x} + E_y(\mathbf{r})\mathbf{y} = E_x(\mathbf{r})(\mathbf{x} + \rho(\mathbf{r})\mathbf{y}) \tag{5}$$

where:

$$\rho(\mathbf{r}) = \frac{E_y(\mathbf{r})}{E_x(\mathbf{r})} \tag{6}$$

is a complex factor representing the polarization ratio. In (5), the wave propagation is assumed to be in the $\mathbf{z}$ direction and introduces no loss of generality. Respectively, $\mathbf{x}$, $\mathbf{y}(\hat{h}, \hat{v})$ represent the scattering or polarimetric basis vectors. One should note that the alignment of the polarimetric basis vectors $\mathbf{x}$, $\mathbf{y}(\hat{h}, \hat{v})$ is arbitrary. The $\mathbf{x}$ alignment may be set at any angle α and the $\mathbf{y}$ alignment can be found by a 90-degree right-hand rotation around the line of sight (LOS), i.e., $\alpha + 90°$. It is, however, imperative to be consistent throughout the entire formulation, in particular, when considering different sensors.

The field complex vector in (5) is general. It can be partially or completely polarized, or completely depolarized. The Stokes vector or parameters are a set of suitable products that can comprehensively describe the polarization state and nature of EM radiation for such general waveforms. The Stokes vector associated with a partially-polarized EM wave (5) is given by [1, 8, 14]:

$$\mathbf{S} = \begin{bmatrix} S_0 \\ S_1 \\ S_2 \\ S_3 \end{bmatrix} = \begin{bmatrix} \left\langle |E_x|^2 \right\rangle + \left\langle |E_y|^2 \right\rangle \\ \left\langle |E_x|^2 \right\rangle - \left\langle |E_y|^2 \right\rangle \\ \left\langle E_x^* E_y + E_x E_y^* \right\rangle \\ j \left\langle E_x^* E_y - E_x E_y^* \right\rangle \end{bmatrix} \tag{7}$$

where $\langle \ldots \rangle$ represents temporal or local spatial averaging. The first vector component S_0 in (7) represents the total power density of the partially-polarized field. The remaining vector components S_1, S_2, S_3 model the polarized component of the EM field, i.e., for an unpolarized EM wave:

$$S_1 = S_2 = S_3 = 0 \tag{8}$$

Decomposing the partially-polarized EM wave into completely polarized and completely depolarized field components using (5), gives:

$$\mathbf{E}^P(\mathbf{r}) = E_x^P(\mathbf{r})(\mathbf{x} + \rho_P(\mathbf{r})\mathbf{y}) \tag{9}$$

$$\mathbf{E}^U(\mathbf{r}) = E_x^U(\mathbf{r})(\mathbf{x} + \rho_U(\mathbf{r})\mathbf{y}) \tag{10}$$

so:

$$\mathbf{E}^{Total}(\mathbf{r}) = \mathbf{E}^P(\mathbf{r}) + \mathbf{E}^U(\mathbf{r}) \tag{11}$$

One obtains for the associated Stokes components:

$$S_1^U = S_2^U = S_3^U = 0 \tag{12}$$

and

$$S_0^U = 2\left\langle \left|E_x^U\right|^2 \right\rangle \quad (|\rho_U(\mathbf{r})| = 1) \tag{13}$$

Also:

$$S_0^{Total} = S_0^U + \sqrt{\left(S_1^P\right)^2 + \left(S_2^P\right)^2 + \left(S_3^P\right)^2} \tag{14}$$

Alternatively:

$$\mathbf{S}^{Total} = \begin{bmatrix} 2\left\langle \left|E_x^U\right|^2 \right\rangle \\ 0 \\ 0 \\ 0 \end{bmatrix} + \left|E_x^P\right|^2 \begin{bmatrix} \left(1 + |\rho_P|^2\right) \\ \left(1 - |\rho_P|^2\right) \\ 2\mathrm{Re}\left(\rho_P\right) \\ 2\mathrm{Im}\left(\rho_P\right) \end{bmatrix} \tag{15}$$

One may also parameterize the Stokes vector in terms of the EM wave polarization ellipse as:

$$\mathbf{S} = \begin{bmatrix} S_0 \\ S_1 \\ S_2 \\ S_3 \end{bmatrix} = I_\alpha \begin{bmatrix} 1 \\ m\cos(2\chi)\cos(2\psi) \\ m\cos(2\chi)\sin(2\psi) \\ m\sin(2\chi) \end{bmatrix} \tag{16}$$

where I_α denotes the total power of the partially-polarized wave (aligned at angle α as described previously) , and m is the degree of polarization given by (using (12)–(14)):

$$m = \frac{S_0^{Total} - S_0^U}{S_0^{Total}} = \frac{\sqrt{(S_1)^2 + (S_2)^2 + (S_3)^2}}{S_0} \tag{17}$$

In (16), χ and ψ are the characteristic parameters describing the EM wave polarization ellipse, i.e., the *ellipticity* and *rotation angles.* As seen from (12)–(14) and (16)–(17), the characteristic parameters χ and ψ describe the polarized portion of the EM wave. As such, the wave polarization and hence the Stokes vector can be mapped onto a 3-dimensional manifold with space angles (χ, ψ). The completely-polarized waves will be located on a sphere of radius I_α (i.e., the *Poincaré* sphere), while the partially-polarized waves lie inside the sphere, i.e., radius mI_α.

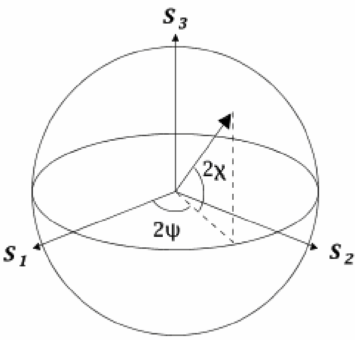

Figure 1. Poincaré sphere, stokes vectors representation.

It is useful to have the analytic representation of some Stokes vector related parameters and products for a partially polarized EM waveform.

The degree of linear polarization is:

$$m_L = \frac{\sqrt{(S_1)^2 + (S_2)^2}}{S_0} = m\cos(2\chi) \tag{18}$$

The circular polarization ratio is:

$$\begin{aligned}\rho_C &= \frac{S_0 - S_3}{S_0 + S_3} = \frac{1 - m_L\tan(2\chi)}{1 + m_L\tan(2\chi)} \\ &= \frac{1 - \sqrt{m^2 - m_L^2}}{1 + \sqrt{m^2 - m_L^2}}\end{aligned} \tag{19}$$

The polarization ratio phase is:

$$\delta = \arctan\left(\frac{S_3}{S_2}\right) \tag{20}$$

The polarization ratio magnitude angle is:

$$2\alpha_\rho = \arccos\left(\frac{S_1}{m\,S_0}\right) \quad (\tan(\alpha_\rho) = |\rho|) \tag{21}$$

And:

$$2\chi = \arctan\left(\frac{S_3}{\sqrt{(S_1)^2 + (S_2)^2}}\right) = \arctan\left(\frac{S_3}{m_L S_0}\right) \tag{22}$$

$$2\psi = \arctan\left(\frac{S_2}{S_1}\right) \tag{23}$$

4. COMPACT POLARIMETRY

The identity of a target interacting with the EM field and/or wave is established via formulation of scattering and by virtue of a scattering operator or matrix. Although as theoretically discussed earlier, performance of such fully-polarized radar system (i.e., quadrature-polarized) is unique and has no substitute in providing complete target backscattering information, it comes with an attendant cost, e.g., lower radar swath coverage, higher antenna transmitter power requirements. As a result, the concept of "partial polarimetry" or "compact polarimetry" has emerged in recent years and several papers on the subject have been published [10–12, 15, 16]. The main objective of this line of research is to achieve certain appealing characteristics of a fully-polarized system without actual realization of a quadrature-polarized system. Partial or dual polarimetry is essentially a step up from a single channel system towards the fully polarimetric system that is an effective strategy when the polarimetric system resources are limited or not available. It is also compatible as an optional mode for a fully polarimetric radar system [9].

As addressed, the backscattering measurements using polarimetric sensors operating at any wavelength or frequency are optimized and the extracted information maximized using Stokes or equivalent to Stokes parameters. It has been demonstrated that partial or compact polarimetry can reproduce full or quadrature-polarized system output products and information [12, 16], e.g., scattering or coherency matrix, by incorporating certain *a priori* information such as reflection and rotation symmetry. Nonetheless, Stokes vector parameterization and analysis represents the identifying nature and characteristics of compact or dual-pol polarimetry.

In a compact polarimetry scenario or dual polarization radar/SAR system, a single polarization EM signal is transmitted (illumination) and the backscattered EM signal is coherently received in two orthogonal polarizations. The choice of the transmit signal is arbitrary, i.e., any polarization, as well as the choice for two orthogonal receive basis polarizations that construct a complete 2-dimensional space to characterize the scattered (in general, partially polarized) EM signal.

Judicious selection of these polarization sets for transmission and reception can optimize the system architecture and satisfy the operational requirements for applications of interest. Any assumed orthogonal polarization set at the receiving end, maximizes the backscattering information through constitution of a complete vector space. However, the choice of polarization basis at reception can affect and optimize radar design with respect to reliability, architecture, mass and power considerations. The nature of the application and targets of interest determines the optimal transmitted polarization. For instance, applications manifesting rotational invariance imply a requirement for transmitted circular polarization (CT). Circular polarization transmit and linear (i.e., h and v) polarization receive mode (CTLR) has been found to be the optimum architecture for lunar or planetary exploration and a good alternative to linear polarization for Earth-observing SAR systems [9]. One of the initial compact polarimetric modes, referred to as the $\frac{\pi}{4}$ mode [11, 17], utilizes a transmitted field polarized at 45° and a linear polarization orthogonal set on receive (e.g., h, v). The $\frac{\pi}{4}$ mode is successful in decomposition analysis involving scenes with scatterers predominantly oriented in horizontal and vertical directions. Both of these mixed-polarity modes, CTLR and $\frac{\pi}{4}$, enjoy extensive meteorological radar heritage [18, 19]. Also, end-to-end circular polarimetry, i.e., Circular polarization transmit and Circular polarization receive mode (i.e., dual circular polarimetric (DCP)) has an extensive heritage in radar astronomy [20–23].

The scattering vectors associated with the described modes CTLR, DCP, and $\frac{\pi}{4}$ can be expressed in terms of the standard quad-pol scattering matrix components as following:

$$\mathbf{k}_{CTLR} = \frac{1}{\sqrt{2}}\begin{bmatrix} S_{hh} + jS_{hv} \\ jS_{vv} + S_{vh} \end{bmatrix} \tag{24}$$

$$\mathbf{k}_{DCP} = \begin{bmatrix} S_{RR} \\ S_{RL} \end{bmatrix} \tag{25}$$

where "R" and "L" denote right and left circular polarizations, and:

$$\mathbf{k}_{\frac{\pi}{4}} = \frac{1}{\sqrt{2}}\begin{bmatrix} S_{hh} + S_{hv} \\ S_{vv} + S_{vh} \end{bmatrix} \tag{26}$$

The described compact polarimetry fundamentals are similar to the theoretical foundation that the present multisensor interworking and fusion proposal is based on. In brief, the core methodology is to maximize the extracted backscattering information by: 1) modeling and full characterization of the scattered EM field using two coherent orthogonal polarizations, chosen based on the system design and architecture requirements; and 2) designing an optimal compact polarimetry mode, or essentially transmit or illumination optimization for intended applications based on respective requirements and constraints.

5. EM FIELD INTENSITY PRODUCTS AND OBSERVABLES

It can be shown that the Stokes vector associated with a scattered EM wave (16) is constructed by measuring the field intensity at 4 polarizations or alignments I_α, I_β, I_γ, I_σ. The alignment angles α, β, γ, σ may conventionally be set at 0°, 45°, 90°, 135° for ease of computations. The choice of these 4 angles is arbitrary but may involve more complicated computations.

One can show that under any polarization rotation, the first Stokes parameter S_0 is invariant and equal to sum of intensities of 2 orthogonal alignments:

$$S_0 = I_\theta + I_{\theta+90} \quad (for\ \ all\ \ \theta) \tag{27}$$

Thus:

$$S_0 = \frac{1}{2}\left(I_\alpha + I_{\alpha+90} + I_\beta + I_{\beta+90}\right) \tag{28}$$

or in the special case:

$$S_0 = \frac{1}{2}\left(I_0 + I_{45} + I_{90} + I_{135}\right) \tag{29}$$

Other Stokes parameters can be derived using a similar approach. More specifically:

$$S_1 = I_0 - I_{90} \tag{30}$$

$$S_2 = I_{45} - I_{135} \tag{31}$$

and:

$$S_3 = \frac{1}{2}\left[\begin{array}{c}\left(m^2-4\right)\left(I_0^2+I_{45}^2+I_{90}^2+I_{135}^2\right)+2\left(m^2+4\right)\left(I_0 I_{90}+I_{45} I_{135}\right) \\ +2m^2\left(I_0 I_{45} + I_0 I_{135} + I_{45} I_{90} + I_{90} I_{135}\right)\end{array}\right]^{\frac{1}{2}} \tag{32}$$

where m is the degree of polarization. The described Stokes vector, parameters and related quantities constitute a unified frame of observables for the scattered wave (fully or partially polarized) analysis throughout a wide EM spectrum. As such, it can be used to formulate the interworking and fusion of SAR and EO polarimetry for advanced target exploitation.

As an example, for the observed scattered field intensity that can be compared and fused for enhanced exploitation, consider the incident EM field with a general polarization (16). The scattered field by a trihedral corner backscatter is characterized a unitary 2×2 scattering matrix. From (27)–(31), one can write:

$$\begin{aligned} I_0 &= \frac{S_0 + S_1}{2} \\ I_{90} &= \frac{S_0 - S_1}{2} \\ I_{45} &= \frac{S_0 + S_2}{2} \\ I_{135} &= \frac{S_0 - S_2}{2} \end{aligned} \tag{33}$$

Simulation depicted in Figure 2 shows the above scattered field intensity variations in terms of the input EM field polarization variations or choice of transmitted polarization, i.e., the ellipticity and rotation angles (χ, ψ). The results provide a tool to compare

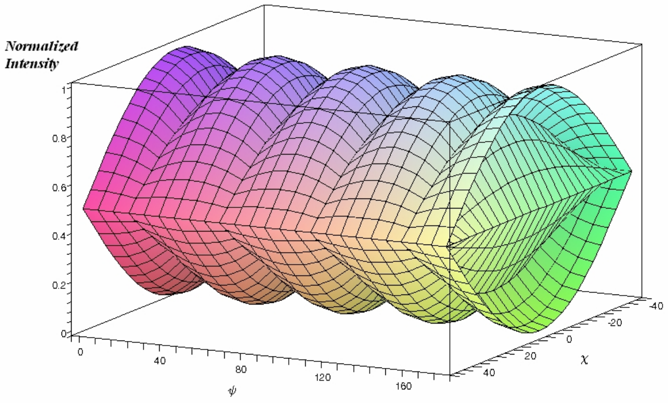

Figure 2. Trihedral corner reflector scattered field total intensity in four manifolds, i.e., I_0, I_{45}, I_{90}, I_{135} (general illumination polarization (χ, ψ)).

or combine polarimetric SAR scattering products with other EM polarimetric sensor (e.g., EO) products based on a robust and accurate theoretical foundation. The significance of these results are better appreciated when considering that standard EO polarimetric products are typically expressed in terms of four field-intensity outputs (i.e., I_0, I_{45}, I_{90}, I_{135}) of polarization filters associated with the four described angles. Hence, the means for effective fusion is provided.

Fusion of the EM polarimetric sensors for advanced exploitations is carried out within the described analytic frame for characterization of the partially coherent scattered field and by the virtue of the Stokes vector and products. Stokes parameters and metrics are derived using inputs from radar/SAR and EO sensors (e.g., intensity and/or phase data, focused and/or unfocused imagery) based on the detailed analytic descriptions. These vectors are then combined and fused in an optimal manner providing enhanced exploitation capability for the remote sensing scenario or target of interest. For instance, improved detection can be achieved by simple addition or superposition of targets Stokes 4-vector derived from the radar and EO sensors. Since typical targets of interest (e.g., manmade) exhibit a higher degree of polarimetric coherence (for both radar and optical frequencies) compared to the randomly distributed clutter, target discrimination ability is improved. It is evident that for targets with certain characteristic or distinct Stokes components, combination of Stokes parameters must be tailored accordingly to ensure optimal fusion. Sensor data fusion for advanced exploitation can also be achieved by extracting target information from its observables using one sensor, and incorporating this information to calibrate and optimize products associated with the other sensor. For example, targets roll or orientation angle can be estimated by using radar/SAR polarimetric data and be applied to determine the optimal alignment of the EO polarization filter (as described above) to enhance the EO polarimetric image quality.

6. CONCLUSIONS

The described EM polarimetry fusion within different bands must be carried out within a robust theoretical framework based on the physics of partially polarized EM waves scattered at different operating wavelengths. Using this framework, sensor fusion can yield a significant advancement in target recognition due to the following: target scattering characteristics (i.e., identity) are better-established in a wider range of the EM spectrum, even if this spectrum expansion is incoherent (i.e., incoherent bandwidths); polarimetric backscatter characteristics for certain target classes of interest are consistent throughout various regions of the EM spectrum (e.g., polarization selectivity for manmade objects). Fusion of EM polarimetric returns in different bands can, in principle, enhance the contrast of such objects/targets compared to those with low or without the addressed polarization selectivity (e.g., clutter). The described EM polarimetric nature (i.e., polarization selectivity) manifested in different regions of the spectrum can be effectively exploited for modification and calibration purposes.

The proven potent and fast growing field of partial or compact polarimetry is established based on fundamentals similar to the theoretical foundation that the present multisensor interworking and fusion proposal is based on. The core methodology is to maximize the extracted backscattering information by:

I. modeling and full characterization of the scattered EM field using two coherent orthogonal polarizations, chosen based on the system design and architecture requirements;
II. designing an optimal compact polarimetry mode, or essentially transmit or illumination optimization for intended applications based on respective requirements and constraints.

Here, the described methodology and/or analytic tool is used to formulate and maximize common information in the polarimetric backscattered field from different sensors (e.g., radar/SAR and optical) for advanced fusion.

To provide a means for advanced exploitation and recognition through an optimal combination of sensor data (e.g., SAR and EO), the following directions are proposed:

1. Secure polarimetric data for a certain target class (or classes) of interest using radar and EO sensors;
2. Formulate/format the data in terms of analytic EM wave vectors (Stokes vectors and parameters); and
3. Investigate scattered EM wave polarization characteristics related to the physics of the target that are consistent in all (or both) EM regions for enhanced fusion calibration and exploitation in one domain using the data and target characteristics from the other domain.

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