POLARIMETRIC SAR IMAGE VISUALIZATION AND INTERPRETATION WITH COVARIANCE MATRIX INVARIANTS

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1. INTRODUCTION

With the launch of Radarsat II and ALOS PALSAR satellites, fully polarimetric SAR images have become available to the earth observation community. Large polarimetric SAR images require visualization schemes for image browsing and interpretation. Methods should be easy to understand and simple to implement. Because the fully polarimetric SAR image consists of 8 parameter layers it is not straightforward to visualize. A human eye does not sense polarization and therefore there is no natural way to present polarization information. Currently two representations are mostly used; polarization RGB plot and entropy-alpha [1] HSI plot [2]. In the simple RGB approach polarization channel powers are mapped to red, green and blue color channels. this method is fast, but its color scale varies from one image to another. The entropy-alpha HSI plot is a much more elaborated approach and is easy to interpret but the parameters are difficult to calculate and the resulting image has lower resolution than the original. To overcome these difficulties, we have proposed alternative ways to parametrize and interpret polarimetric SAR images [3]. The proposed parameters are based on normalized covariance matrix invariant properties and are related to common polarimetric descriptors, including parameters used in optical polarimetry.

In this study we review existing polarimetric SAR image visualization schemes and review some interesting new approaches based on normalized covariace matrix. The normalized covariance matrix based parameters provide fast visualization and provide interesting ways of interpretation of polarimetric SAR image. In the interpretation we utilize concepts from SAR polarimetry but also from optical polarimetry.

2. PARAMETERS FOR POLARIMETRIC SAR IMAGE

A polarimetric SAR image pixel is represented by a complex scattering matrix $\mathbf{S}$, normally measured in horizontal-vertical (H V) polarization basis and defined in BSA (Backscattering Alignment)[4] convention:

$$\mathbf{S} = \begin{bmatrix} S_{HH} & S_{HV} \\ S_{VH} & S_{VV} \end{bmatrix} \tag{1}$$

The coveriance matrix is formed by first forming the measurement vector (here for the monostatic case, in Pauli basis)

$$\vec{k} = \frac{1}{\sqrt{2}} \left[S_{HH} + S_{VV}, S_{HH} - S_{VV}, S_{HV} + S_{VH} \right]^T \tag{2}$$

and the covariance matrix is then defined by

$$\langle \mathbf{C} \rangle = \left\langle \vec{k}\vec{k}^{\dagger} \right\rangle \tag{3}$$

For polarimetric interpretation it is convenient to examine total power and polarimetric information separately. For this reason we form a covariance matrix normalized by total backscattering power as

$$\mathbf{N} = \left\langle \vec{k}^{\dagger}\vec{k} \right\rangle^{-1} \left\langle \vec{k}\vec{k}^{\dagger} \right\rangle = \frac{\mathbf{T}}{\text{trace}(\mathbf{T})} \tag{4}$$

$$N_{11} = \frac{\left\langle |S_{hh} + S_{vv}|^2 \right\rangle}{\text{span}}. \tag{5}$$

The Cloude-Pottier decomposition [5] uses similar formulation and, therefore, parameters proposed below are easy to relate with the common entropy-alpha parameters.

For polarimetric interpretation we define the **scattering diversity** [3]

$$\hat{H} = \frac{3}{2}\left(1 - \|\mathbf{N}\|_F^2\right). \tag{6}$$

The scattering diversity is low, when it is possible to identify a single coherent scattering mechanism responsible for most of the scattering. The scattering diversity is high when there are many scattering mechanisms and it is not possible to identify single coherent mechanism behind the reflection. The parameter is closely related to polarimetric entropy and average depolarization, but is simpler to calculate.

Another convenient parameter is **surface scattering fraction** [3], defined here as

$$N_{11} = \frac{\left\langle |S_{hh} + S_{vv}|^2 \right\rangle}{\text{span}}. \tag{7}$$

The parameter tells the fraction of received power reflected back by a roll invariant single bounce reflection. When the parameter is equal to 1, all backscattering comes from odd-bounce scattering; if the parameter is equal to 0, there is no odd-bounce scattering present. It can be also interpreted as a fraction of RL (right-left) polarized response from total backscattered power in circular basis. This parameter is closely related to alpha parameters in Cloude-Pottier decomposition approach [5].

We use double bounce fraction in a similar manner. Additionally, we study the relation of off diagonal power to main diagonal power in the covariance matrix.

3. VISUALIZATION OF POLARIMETRIC SAR IMAGE

The most common ways to visualize a multilayer image is three channel color coding, where three parameters modulate three color channels. For example in RGB color coding three parameters modulate red, green and blue color channel, respectively. Another possibility is to use HSI representation, where only one channel modulates directly the color (hue) and other parameters contol color saturation and image intensity. It depends on the nature of selected parameters, which scheme is preferable. For example entropy, alpha and span suit well for HSI visualization [2]. Here we use both and discuss the benefits and drawbacks of these approaches. Unfortunately it is difficult to present more than three parameters in a single image and, therefore, the selection of most relevant parameters for a given application is a essential part of visualization.

An interesting visualization can be arranged by using normalized covariance matrix main diagonal elements. Because we have three variables, whose sum is constrained to one, we can use the classical ternary diagram to construct an easily interpretative triangular color space, where every corner represents a pure scattering mechanism and in the middle of the triangle all scattering mechanisms are equiprobable and the color is white. In this diagram, the relative strength of three basic scattering

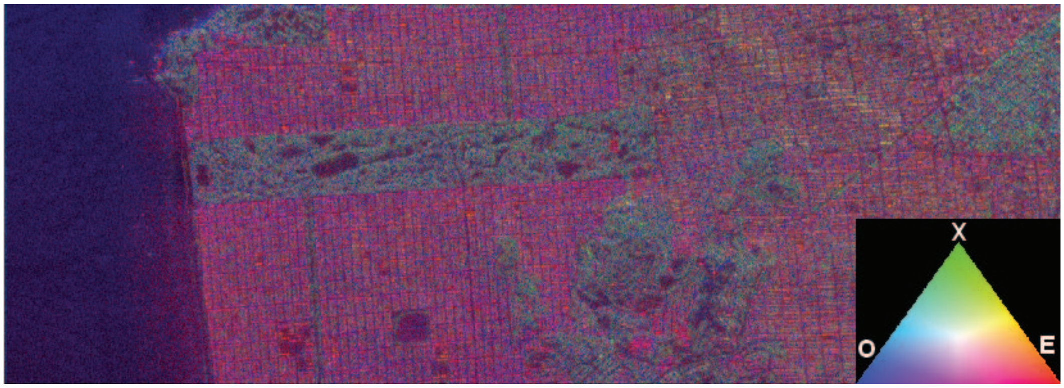

Fig. 1. Fully polarimetric SAR (AIRSAR) image of San Francisco Bay presented in ternary-RGB color scale. The color of a pixel is determined by relative strength of basic scatterers represented by Pauli matrices (N_{11}, N_{22}, N_{33}) as shown in ternary diagram in the lower right. The letters denote three pure scattering mecanism, odd bounce (O), even bounce (E) and cross polarizer (X). The intensity of a pixel is determined by logarithm of total backscattered power (span).

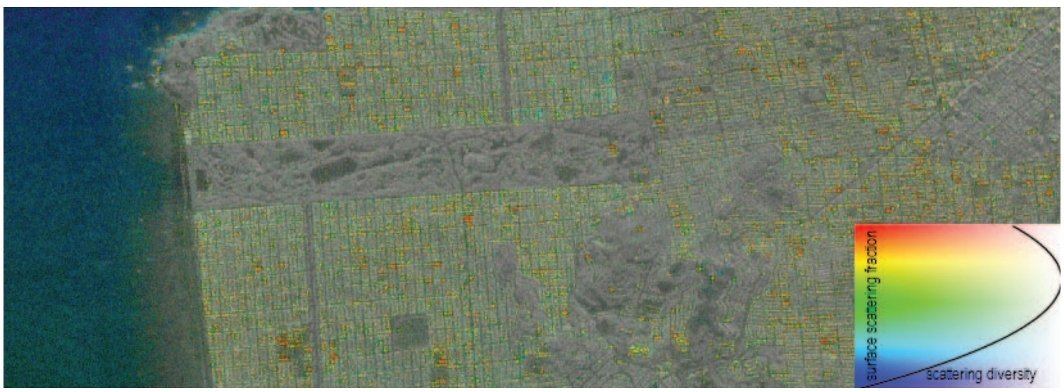

Fig. 2. Fully polarimetric SAR (AIRSAR) image of San Francisco Bay in multiresolution-synoptic visualization, where hue is described by surface scattering fraction, saturation by scattering diversity and intensity by $\log(\text{span})$. Span and surface scattering fraction are averaged over a 4x4 window and scattering diversity is calculated for a 20×20 window. Gray denotes areas, where polarimetric information is random (parks and forest), blue denotes single-bounce scattering and red double-bounce scattering.

mechanisms described by Pauli matrices can be represented unambiguously. Normally also eigenvectors are not far from the original axis, i.e. odd-bounce, even-bounce and cross-polarizer. This means that coherency matrix off-diagonal elements are often insignificant. Therefore using only diagonal elements of the normalized coherency matrix gives results similar to those from eigenvalue based methods. Example of this visualization scheme is presented in Figure 1. Single bounce scattering from the sea is blue, double bounces from urban areas appear red and cross polarization response from forest is green.

In another example we use scattering diversity and surface scattering fraction parameters to create a plot similar to entropy-alpha HSI plot [2]. The method utilizes hue-saturation-intensity color space to represent the SAR image scattering mechanism ($\bar{\alpha}$ angle), entropy and intensity. The main benefit of the scheme is the image independent color space and constant scaling of parameters, as opposed to the RGB representation, where colors of the image depend on the image intensity distribution. In [6] the method was further developed by proposing that intensity and hue layers of the image can be presented with a resolution which is higher than that of the entropy layer. The proposed scattering diversity and surface scattering fraction suit particularly well for this representation. They are fast to calculate even for big images and their interpretation is straightforward. In Figure 2 is presented a polarimetric AIRSAR image in HSI representation where color is controlled by surface scattering fraction and color saturation is driven by scattering diversity. The intensity channel is controlled by total backscattered power. See appears blue, building appear green and red and forest is gray, because color saturation is low where scattering mechanism is random. This approach benefits from averaging of scattering diversity parameter and noise in polarimetric information content compared to previous approach is reduced. However averaging brings an additional step to calculations.

4. CONCLUSIONS

In this abstract we have presented some visualization techniques suitable for fully polarimetric SAR images. The presented polarimetric parametes are suitable for large images and have straightforward interpretation. In the conference a more detailed comparison with existing techniques and discussion about image interpretation will be given.

5. REFERENCES

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