Comparison of Methods for Classification of Land Cover Using Polarimetric SAR Data

Ernst Krogager, Doroteya K. Staykova, Vito Alberga, Danish Defence Research Establishment, Denmark
Andreas Danklmayer, German Aerospace Centre (DLR), Germany
Madhu Chandra, Chemnitz University of Technology, Germany

Abstract

Polarimetric SAR data are coherent by nature of the principle of operation. However, most often incoherent approaches are chosen for the post-processing in order to apply conventional averaging and statistical methods. For this purpose, covariance and coherency matrices are typically formed from the complex raw data, and a variety of incoherent analysis and decomposition methods have been proposed for the further information extraction. Alternatively, the complex data may be used on a pixel by pixel basis to extract information at the highest possible resolution. By the latter approach, absolute phases have to be taken into account, and straightforward averaging of the coherent quantities cannot be applied. However, it is still possible to perform averaging of individually extracted real parameters, and as we shall show, the coherent data can indeed be averaged after proper phase normalization. In this work, we have considered both coherent and incoherent approaches for the purpose of quantitatively comparing the utility of the various approaches. The analysis procedure is based on a series of classification tests on many different polarimetric parameters derived after applying the different theoretical methods. Several classification methods have been applied, and hence, the work comprises a comparison of the classification potential of different polarimetric descriptors as well as a comparison of the performance of different classifiers for the type of data under investigation. Data from the Danish EMISAR have been used.

1 Summary of theories

1.1 Coherent processing methods

1.1.1 Scattering matrix elements

The data directly detected by the polarimetric SAR sensor are represented by the well known 2x2 complex Sinclair scattering matrix [S]. The most straightforward way to use this information is to use the three magnitudes HH, HV, and VV, assuming a linearly polarized system with horizontal and vertical antennas, and assuming reciprocal conditions for the typically used mono-static configuration. However, to use the full amount of information, complex values must be used. Transformation to any other basis, notably the circular basis and the basis in which the scattering matrix is diagonal, is easily accomplished by well known procedures [1].

1.1.2 Huynen-Euler parameters

The target characteristic parameters associated with the diagonal form of the scattering matrix, known as the Huynen-Euler parameters [2], are the following: *m,* the maximum polarization, i.e., the maximum attainable response; ψ, the orientation angle; τ_m, the helicity angle, i.e., the ellipticity of the optimum polarization; ν, the skip angle, related to the concept of odd and even bounce reflections; γ, the characteristic angle, related to the capability of the target to change the polarization of the incoming wave; ζ, the absolute phase which is usually disregarded.
The orientation angle and the helicity angle characterize the optimum polarization for the target.

1.1.3 Coherent target decompositions

In this category, we have studied the three main coherent decomposition theorems, commonly referred to as the Pauli, the Krogager and the Cameron decompositions, respectively.

1.1.3.1 Pauli decomposition

The most commonly known and applied coherent decomposition is the Pauli decomposition, whereby a generic [**S**] matrix can be written as:

$$[\mathbf{S}] = a\begin{bmatrix}1 & 0\\0 & 1\end{bmatrix} + b\begin{bmatrix}1 & 0\\0 & -1\end{bmatrix} + c\begin{bmatrix}0 & 1\\1 & 0\end{bmatrix} \qquad (1)$$

where *a*, *b*, and *c* are complex quantities representing, respectively, single-bounce, double-bounce, and 45° rotated double-bounce scattering components.

1.1.3.2 Krogager decomposition

According to this approach, the complex, symmetric scattering matrix can be decomposed into three components, as if the scattering were due to a sphere, a diplane and a right- or left-wound helix (SDH),

$$[\mathbf{S}] = e^{j\phi}\left\{e^{j\phi_s} k_s [\mathbf{S}]_s + k_d [\mathbf{S}]_{d(\theta)} + k_h [\mathbf{S}]_{h(\theta)}\right\} \quad (2)$$

The values of the coefficients are easily obtained from the elements in the circular basis [3].

1.1.3.3 Cameron decomposition

A general symmetric [S] matrix may be characterized by the target's tendency of being more or less symmetric with respect to an axis in the plane orthogonal to the radar line-of-sight, and a distinction can be made between the most dominant and the least dominant symmetric target components [4],

$$[S]_{rec} = [S]_{sym}^{max} + [S]_{sym}^{min} \quad (3)$$

1.1.3.4 Principal components analysis

An interesting approach to combining coherent and incoherent methods was suggested by Lüneburg [5], based on the diagonalization of the covariance matrix and on the subsequent derivation of a set of [**S**] matrices related to its eigenvectors. In this way, the response from distributed targets can be expressed as a coherent sum of independent scattering mechanisms. The important aspect is that [**S**] is rendered as the coherent sum of elementary scattering mechanisms weighed by coefficients derived via an incoherent step. Hence, random scatterers are re-expressed in terms of scattering matrices.

1.1.4 Coherent phase normalization

A key point in relation to processing coherent observables is the handling of phase information. It is well known that coherent data cannot be meaningfully integrated and averaged due to the absolute phase associated with each pixel. However, by applying phase normalization, averaging becomes possible, and in fact this is somehow comparable to the phase alignments associated with the synthetic aperture formation itself [1][6].

In a simplified formulation, an average scattering matrix can be obtained by the following operation (shown here only for the HH element):

$$\left\langle S_{hh\,norm}\right\rangle = \frac{1}{N}\sum_{i=1}^{N} e^{j\varphi^i} S_{hh}^i \quad (4)$$

which amounts to ensemble averaging of the N involved samples, φ^i being the normalization phase term. The choice of normalization phase is crucial, and whereas the HH element has been used for such purposes in the past, a number of possible choices are available, e.g., the phase of the off-diagonal element of the circular basis, which represents odd-bounce contributions and hence, for each individual pixel, defines a phase-reference related to the physical properties of the target. This corresponds to the first term of both (1) and (2). Similarly, phase normalization using the diplane component is a relevant option.

1.2 Incoherent processing methods

1.2.1 Covariance and coherency matrices

These are the well known and widely used 3×3 matrices obtained from the [S] matrix elements. The covariance matrix is formed from a straightforward lexicographic vectorization of the scattering matrix,

$$\mathbf{k}_{(3)L} = \left[S_{hh}, \quad \sqrt{2}S_{hv}, \quad S_{vv} \right] \quad (5)$$

while the coherency matrix is formed on the basis of the Pauli expansion,

$$\mathbf{k}_{(3)P} = \tfrac{1}{\sqrt{2}}\left[S_{hh}+S_{vv}, \quad S_{hh}-S_{vv}, \quad 2S_{hv} \right] \quad (6)$$

1.2.2 Incoherent target decompositions

1.2.2.1 Freeman decomposition

The Freeman decomposition [7] describes the scattering as due to three physical mechanisms, namely first-order Bragg surface scatter (s), a double-bounce scattering mechanism (d) and canopy (or volume) scatter from randomly oriented dipoles (v). According to this model, the measured power P may be decomposed into three quantities:

$$P_s = f_s\left(1+|\beta|^2\right), P_d = f_d\left(1+|\alpha|^2\right), P_v = \tfrac{8}{3} f_v \quad (7)$$

Reflection symmetry is assumed, implying:

$$\left\langle S_{hh}S_{hv}^*\right\rangle = \left\langle S_{hv}S_{vv}^*\right\rangle = 0 \quad (8)$$

Moriyama et al. [8] proposed to adapt the Freeman decomposition to the specific case of urban areas where (8) does not hold. The model of Moriyama can be combined with the original Freeman approach by using the correlation coefficient between co- and cross-polar terms to decide which one to use. With cross-correlation values close to 1, the urban area formulation is chosen, while the original formulation is chosen for values close to 0.

1.2.2.2 Cloude-Pottier decomposition

Several decomposition approaches are based on the eigenvalues and eigenvectors of the covariance and coherency matrices. In particular, the entropy, alpha, anisotropy (H,α,A) decomposition proposed by Cloude and Pottier [9] has been widely adopted for classification of terrain, crop, and other remote sensing applications where resolution is not a major concern. It should be noted that application of these techniques often involve up to several statistical assumptions which may only hold to a certain extent.

Figure 1 SAR image of the considered scene in the Halsskov area with training areas marked.

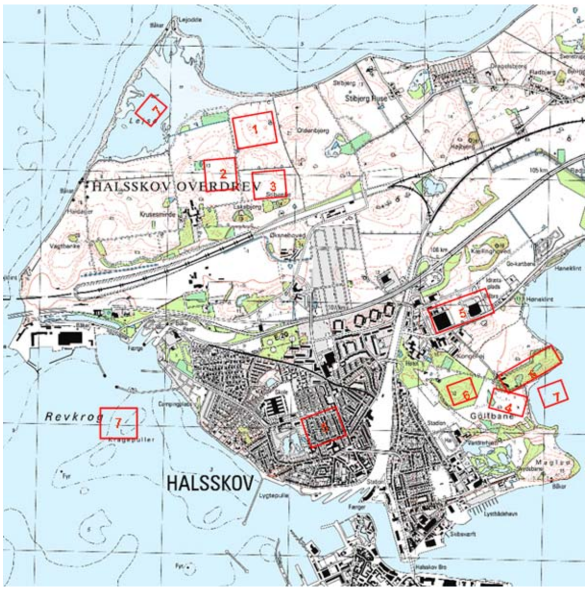

Figure 2 Map of scene with training areas marked. © Kort & Matrikelstyrelsen

2 Experimental approach

The experimental data used for the tests are from the Danish Great Belt area, acquired by the EMISAR airborne sensor operated by the Department for Electromagnetic Systems (EMI) of the Technical University of Denmark (DTU). The measurement campaign was held in June 1998 and the data consist of C-band scattering matrices measured in the *hv*-basis. The location is about 100 km southwest of Copenhagen at the west coast of Zealand. It includes the Halsskov area at the city of Korsør, its port, the beginning part of the Great Belt East Bridge, several cultivated fields, small tree stands and other general classes of land cover, see **Figure 1** and **Figure 2**.

An averaging window of 3×15 pixel (in range and azimuth, respectively) has been used in order to refer to areas on the ground approximately squared. Noise removal and speckle reduction have been obtained by means of simple boxcar filtering.

A common classification procedure was adopted for all the polarimetric parameters. A set of ground cover classes was defined, and for each of them separated areas of training and test samples with a comparable number of pixels have been identified. Supporting information like airborne pictures, digital maps and ground truth data have also been used in this process.

The following set of seven classes has been defined: “water”, “houses”, “clover”, “trees”, “grass”, “barley” and “pasture”. The class “grass” has been defined referring mainly to a golf course clearly delimited in a digital map. Likewise, the class “houses” is associated with areas of strong backscattering corresponding to city area in this map.

3 Classification algorithms

The primary classifiers considered here are the minimum distance (MD) and the maximum likelihood (ML) classifiers as implemented in the ENVI software package. For the MD classifier no knowledge of the statistics of the data is needed (only the calculated mean value of each class is used), while for the ML classifier this is necessary because the algorithm must be implemented according to the distribution of the data to be classified. Nevertheless, for this study we used the same basic implementation of the ML to classify all the parameters, including the incoherent ones, based on the assumption of Gaussian distribution of the data.

4 Results and discussion

A summary of obtained results is shown in **Figure 3**. In general, as is well known, the ML yields the best performance, but nevertheless, the MD classifier in many cases gives almost exactly the same overall result. Another main finding is that the best results based on coherent formulations are similar to the best results based on the incoherent formulations.

As can be seen, the H,α,A results are rather poor, which is due to the fact that this set of parameters is derived from eigenvalues only, while the information associated with the corresponding eigenvectors is not used. In this sense, the results shown here represent the performance (information content) of the pure H,α,A representation.

As a further comparison, we include two additional results based on a neural net and a Wishart classifier.

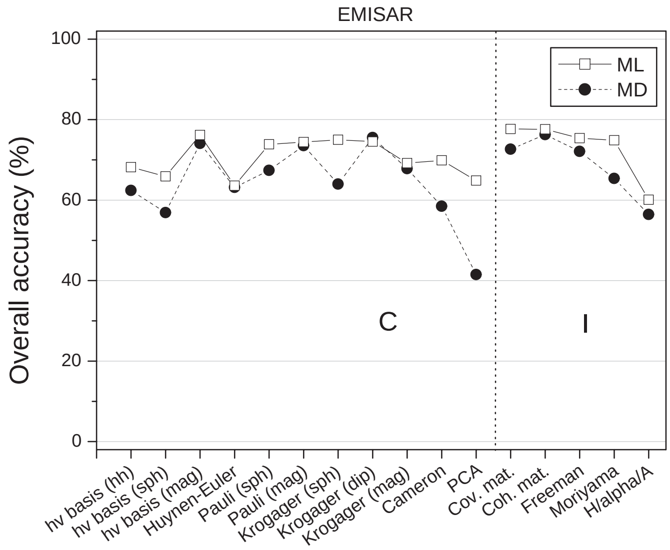

Figure 3 Classification accuracies using MD and ML classifiers. In brackets the phase term used for phase normalization: hh: S_{hh}; sph: sphere component; dip: diplane component; mag: only three magnitudes used.

Using a neural network for the 'hv basis (hh)' resulted in 69.7 % vs. 68.2 % using ML. Using the Wishart classifier of PolSARpro for the 'Cov. mat.' case resulted in 77.9 % vs. 77.7 % using ML.

We note that in [10] the overall results for 'hv basis (mag)', 'Krogager (mag)', and 'Pauli (mag)' were 57.0 %, 87.4 %, and 57.6 %, respectively. As a partial explanation, the results in [10] were obtained using L-band data from the German E-SAR with a resolution of 1.5 m in range and 0.89 m in cross-range, while the EMISAR data used here are C-band data with respective resolutions of 3.0 m and 0.75 m.

5 Conclusions

We have presented a summary of results from a study aiming at a quantitative comparison of coherent and incoherent polarimetric parameters. A key issue is the necessity of averaging in order to optimize the performance. For the coherent methods, a new method for phase normalization was applied, keeping in mind the well known fact that the raw coherent data cannot be meaningfully averaged. Overall, we found quite comparable classification results for the coherent and incoherent formulations. A particularly significant finding is the fact that the applied phase normalization of the coherent parameters yields meaningful results comparable with results of conventional incoherent approaches. The general preference for the conventional methods should therefore be further challenged by follow-on studies, and the use of coherent formulations for classification purposes deserves further attention.

Acknowledgments

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