Compact polarimetry: Neural network assisted reconstruction of full polarimetric information

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1. Introduction

Compact Polarimetry (CP) can be a very attractive design option for space-borne POLSAR systems, leading to reduced payload power consumption, increased azimuth sampling frequency, increased swath width and potentially reduced data downlink rate demand [2]. However, in order to be able to synthesize target responses for any transmitted and received radar polarisation [3], a process to reconstruct full polarimetric (FP) information is needed.

Souyris *et al*. [1] introduced the so-called compact polarimetry π/4 mode, where the target vector is $t_{\mathrm{CP}} = [s_{\mathrm{HH}} + s_{\mathrm{HV}} \quad s_{\mathrm{HV}} + s_{\mathrm{VV}}]^T$ instead of $t_{\mathrm{FP}} = [s_{\mathrm{HH}} \quad \sqrt{2}s_{\mathrm{HV}} \quad s_{\mathrm{VV}}]^T$ as it is for the full polarimetry case. Adopting this, the covariance matrix for compact polarimetry becomes

$$\mathbf{J} = \left\langle t_{\mathrm{CP}} t_{\mathrm{CP}}^{*T} \right\rangle = \begin{bmatrix} |s_{\mathrm{HH}}|^2 + |s_{\mathrm{HV}}|^2 & s_{\mathrm{HH}} s_{\mathrm{VV}}^* + |s_{\mathrm{HV}}|^2 \\ s_{\mathrm{VV}} s_{\mathrm{HH}}^* + |s_{\mathrm{HV}}|^2 & |s_{\mathrm{VV}}|^2 + |s_{\mathrm{HV}}|^2 \end{bmatrix} + \begin{bmatrix} 2\Re\left(s_{\mathrm{HH}} s_{\mathrm{HV}}^*\right) & s_{\mathrm{HH}} s_{\mathrm{HV}}^* + s_{\mathrm{HV}} s_{\mathrm{VV}}^* \\ s_{\mathrm{HV}} s_{\mathrm{HH}}^* + s_{\mathrm{VV}} s_{\mathrm{HV}}^* & 2\Re\left(s_{\mathrm{VV}} s_{\mathrm{HV}}^*\right) \end{bmatrix}. \quad (1)$$

Under the assumption of reflection symmetry, which is the case for natural surfaces, the full polarimetric covariance matrix is thus simplified from nine to five elements [4]:

$$\mathbf{C}_{\mathrm{FP}}^{\mathrm{symmetry}} = \begin{bmatrix} |s_{\mathrm{HH}}|^2 & 0 & s_{\mathrm{HH}} s_{\mathrm{VV}}^* \\ 0 & 2|s_{\mathrm{HV}}|^2 & 0 \\ s_{\mathrm{VV}} s_{\mathrm{HH}}^* & 0 & |s_{\mathrm{VV}}|^2 \end{bmatrix}. \quad (2)$$

Following the same assumption, the second term in (1) can be ignored and the CP covariance matrix reduces to:

$$\mathbf{J}_{symmetry} = \begin{bmatrix} j_{11} & j_{12} \\ j_{12}^* & j_{22} \end{bmatrix} = \begin{bmatrix} |s_{\mathrm{HH}}|^2 + |s_{\mathrm{HV}}|^2 & s_{\mathrm{HH}} s_{\mathrm{VV}}^* + |s_{\mathrm{HV}}|^2 \\ s_{\mathrm{VV}} s_{\mathrm{HH}}^* + |s_{\mathrm{HV}}|^2 & |s_{\mathrm{VV}}|^2 + |s_{\mathrm{HV}}|^2 \end{bmatrix}. \quad (3)$$

To reconstruct the full polarimetric information, Souyris *et al*. [1] introduced an iterative approach to estimate $|s_{\mathrm{HV}}|^2$ from simulated CP information, i.e.

$$\mathbf{C}_{\mathrm{FP}}^{\mathrm{symmetry}} = \begin{bmatrix} j_{11} - |s_{\mathrm{HV}}|^2 & 0 & j_{12} - |s_{\mathrm{HV}}|^2 \\ 0 & 2|s_{\mathrm{HV}}|^2 & 0 \\ j_{12}^* - |s_{\mathrm{HV}}|^2 & 0 & j_{22} - |s_{\mathrm{HV}}|^2 \end{bmatrix}. \quad (4)$$

2. Summary of Contribution and Discussion of Effectiveness

An initial evaluation of Souyris' approach was undertaken using NASA/JPL airborne multi-look data as well as RADARSAT-2 single-look data. Both data cover the same test site, i.e. Muda Merbok in Malaysia. The site was selected to deliberately contain several built-up areas in addition to vegetation and water cover, and as such violates the primary reflection symmetry assumption. The assumption therefore is that in such cases, the compact polarimetry $\pi/4$ mode simulation should be based on (1) rather than (3) as the result data will be closer to actual measured information, even at the expense of increasing the reconstruction error in (4).

Having applied Souyris' reconstruction algorithm on both datasets, the results were evaluated by means of comparing land-cover classification outputs based on the original and reconstructed data. In this context one of the main highlights of this study is the diversity of classes, comprising forest, rivers, rice fields, oil-palm plantations, shrub, and built-up areas. This investigation also extends the discussion to the usage of single-look data encompassing built-up areas.

As part of the efforts to increase the resilience of the reconstruction approach, the full polarimetric information was recovered through an algorithm directed by a back-propagation multi-layer perceptron neural network. This study documents the experience on overcoming the multiplicative noise / speckle characteristic of SAR data through this approach, and presents comparative results by again applying land-cover classification as benchmark.

3. Conclusion

This work introduced a novel neural network based approach to estimate full polarimetric information from simulated compact polarimetry $\pi/4$ mode. The main benefits of the solution are its adaptability and reconstruction resilience in the presence on built-up areas. The proposed approach was compared with Souyris' algorithm on both NASA/JPL airborne multi-look data as well as RADARSAT-2 single-look data over a tropical site containing both natural and man-made features. The reconstruction results were evaluated by comparing target responses by means of assessing the land-cover classification results for both the original and reconstructed data. The preliminary results indicate a significant improvement over built-up areas, while the performance in areas with natural surface, such as forest and shrub areas, is comparable to Souyris' approach.

References

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