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Estimation and segmentation in non-Gaussian POLSAR clutter by SIRV stochastic processes

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Abstract:

In a particular frequency band, the wave-media interactions over distributed areas are generally studied using the polarimetric covariance matrix (called also coherency when vectorizing in the Pauli basis). However, among the difficulties encountered when using POLSAR imagery, one important feature is the presence of speckle. Occurring in all types of coherent imagery, the speckle is due to the random interference of the waves scattered by the elementary targets belonging to one resolution cell. In general, POLSAR data are locally modelled by the multivariate, zero mean, circular Gaussian probability density function, which is completely determined by the covariance matrix.

The recently launched POLSAR systems are now capable of producing high quality images of the Earth's surface with meter resolution. The decrease of the resolution cell offers the opportunity to observe much thinner spatial features than the decametric resolution of the up-to-now available SAR images. Recent studies [1] show that the higher scene heterogeneity leads to non-Gaussian polarimetric clutter modelling, especially for urban areas. One commonly used fully polarimetric non-Gaussian clutter model is the product model [2]: the spatial non-homogeneity is incorporated by modelling the clutter as the product between the square root of a scalar random variable (texture) and an independent, zero mean, complex circular Gaussian random vector (speckle).

For Gaussian polarimetric clutter model, the estimation of the polarimetric coherency matrix is treated in the context of POLSAR speckle filtering. In the context of non-Gaussian polarimetric clutter models, several studies tackled POLSAR parameter estimation using the product model. Spherically Invariant Random Vectors (SIRV) and their applications to estimation and detection in communication theory were firstly introduced by Kung Yao [3]. In the context of POLSAR data, the clutter is modelled as SIRV, a non-homogeneous Gaussian process with random power: its randomness is induced by variations in the radar backscattering over different polarization channels. Consequently, the POLSAR target vector $\overrightarrow{k}$ is defined as the product between the independent complex Gaussian vector $\overrightarrow{z}$ with zero mean and covariance matrix $[M] = E\{\overrightarrow{z}\,\overrightarrow{z}^{\dagger}\}$ (representing the speckle) and the root of a positive random variable τ (representing the texture):

$$\overrightarrow{k} = \sqrt{\tau}\,\overrightarrow{z}, \tag{1}$$

where † denotes the conjugate transpose operator and $E\{...\}$ the mathematical expectation. In Eq. 1, the covariance matrix is an unknown parameter which can be estimated from Maximum Likelihood (ML) theory. Recently, a new adaptive scheme has been introduced for covariance structure matrix estimation in the context of adaptive radar detection under non-Gaussian noise [4]. Because of the implicit algebraic structure of the equation to solve, the corresponding solution is known as the Fixed Point (FP) estimate.

This paper presented a new estimation scheme for deriving normalized coherency matrices and the resulting estimated span with high resolution POLSAR images. The proposed approach couples nonlinear ML estimators with span driven adaptive neighborhoods [5] for taking the local scene heterogeneity into account: the heterogeneous clutter in POLSAR data is described by the SIRV model. Two estimators are introduced for describing the POLSAR data set: the Fixed Point estimator of normalized coherency matrix and the corresponding LLMMSE span. The Fixed Point estimation is independent on the span PDF and represents an approximate ML estimator for a large class of stochastic processes obeying the SIRV model. Moreover, the derived normalized coherency is asymptotically Gaussian distributed.

For SIRV clutter, a new approximate ML distance measure is introduced for unsupervised POLSAR classification. This distance is used in conventional K-means clustering initialized by the $H/\alpha/A$ polarimetric decomposition[6]. Other extensions of the existing unsupervised or supervised POLSAR segmentation methods (e.g. Bayes ML or fuzzy K-means) can be derived by replacing the conventional Wishart distance with the proposed SIRV distance.

The effectiveness of the proposed estimation/segmentation scheme is illustrated by very high resolution ONERA RAMSES X-band POLSAR data.

References

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