SPECKLE REDUCTION AND EDGE DETECTION FOR TERRASAR-X SINGLE-LOOK DUAL-POLARIZATION IMAGERY

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ABSTRACT

The successful launch of TerraSAR-X has provided plentiful opportunities to examine the application of high-resolution dual-polarization spaceborne data. However, the presence of inherent speckles can be observed in TerraSAR-X single-look spotlight intensity data as a result of random interference of backscattered waves from elementary scatterers within an illuminated resolution cell. In this paper, preliminary work on speckle reduction and edge detection of TerraSAR-X single-look dual-polarization spotlight data is reported. Each pixel in TerraSAR-X single-look slant-range dual-polarization (HH and VV polarizations) spotlight data can be represented by a two-dimensional complex vector, i.e.

$$\mathbf{z} = \begin{bmatrix} HH \\ VV \end{bmatrix} = \begin{bmatrix} \Re(HH) + j\Im(HH) \\ \Re(VV) + j\Im(VV) \end{bmatrix}, \tag{1}$$

where the symbols $\Re(.)$ and $\Im(.)$ denote the real and imaginary components, respectively. The signed 16-bit real and imaginary values are calibrated by multiplying with the square root of the calibration factor provided in the annotation file [1]. To simplify the development of the speckle reduction approach, the complex vector $\mathbf{z}$ of a homogeneous area is assumed to be independent and identically distributed as a zero-mean bivariate complex Gaussian, i.e.

$$f(\mathbf{z}) = \pi^{-2}|\mathbf{\Sigma}|^{-1}\exp\left(-\mathbf{z}^{*T}\mathbf{\Sigma}^{-1}\mathbf{z}\right), \tag{2}$$

where $\mathbf{\Sigma}$ is the population covariance matrix. The symbols $*$ and T denote the complex conjugate and transpose, respectively. The operator $|\,.\,|$ refers to the matrix determinant. The population squared radius $2\mathbf{z}^{*T}\mathbf{\Sigma}^{-1}\mathbf{z}$ follows a χ^2 distribution with four degrees of freedom. In most cases the population covariance matrix remains unknown. This parameter can, however, be estimated from the samples based on the maximum likelihood method. As shown in this paper, the exact distribution of the sample squared radius $N^{-1}\mathbf{z}^{*T}\mathbf{S}^{-1}\mathbf{z}$ is a beta distribution, which depends on the vector dimension and the number of samples.

Based on the sample squared radius, a speckle reduction approach is proposed for TerraSAR-X single-look dual-polarization data. The proposed approach was originally inspired by the classical Lee sigma filter [2], but eventually led to a different design. The steps of the proposed approach are as follows:

1) Compute the dual-polarization matrix $\mathbf{Z} = \mathbf{z}\mathbf{z}^{*T}$ for each pixel.
2) Estimate the sample covariance matrix $\mathbf{S}$ within a selected $n \times n$ window.
3) Determine the critical value $\beta_{\alpha;2,N-2}$ from the beta distribution with a desired significance level α.
4) Compute the average dual-polarization matrix by using only those pixels within the window, which fulfill the following criterion:

$$\mathbf{z}^{*T}\mathbf{S}^{-1}\mathbf{z} \le N\beta_{\alpha;2,N-2}\,, \tag{3}$$

where $N=n\times n$. If the number of pixels which fulfills the above criterion is less than or equal to nine pixels, then the average dual-polarization matrix by using a 3×3 window is computed as the output. Fig. 1 presents the selected results from both the proposed approach and boxcar filter, where the TerraSAR-X single-look dual-polarization spotlight test data cover a coastal plain of Kuala Muda in Peninsular Malaysia.

The proposed speckle reduction approach does not retain well point targets and one-pixel wide line features. A constant false alarm rate edge detector, which might be generalized for both point and line detection, is thus introduced based on the Wilks' lambda, i.e.

$$\Lambda = |\mathbf{X}| / |\mathbf{X}+\mathbf{Y}|. \tag{4}$$

Both random matrices $\mathbf{X}$ and $\mathbf{Y}$ have independent p-variate central complex Wishart distributions $CW_p(n, \mathbf{\Sigma})$ and $CW_p(m, \mathbf{\Sigma})$, respectively. The number of samples for $\mathbf{X}$ and $\mathbf{Y}$ are denoted separately by n and m, while $\mathbf{\Sigma}$ is the population covariance matrix. Since $p = 2$ for TerraSAR-X single-look dual-polarization data, the Wilks' lambda is distributed as the product of two

independent beta-distributed random variables B_1 and B_2 with beta(n – 1, m) and beta(n, m), respectively. The exact distribution for the product $w = B_1B_2$ was derived by Steece [3, p. 189]. To detect edges, the processing steps are outlined below:

1) Place an edge template over a pixel i. Fig. 2(d) shows an example set of edge templates of 5×5 pixels with different edge orientations. In each template, there are two test regions, namely $r1$ and $r2$, containing n and m pixels, i.e. $n = m = 10$.

2) Compute **X** and **Y**:

$$\mathbf{X} = \sum_{k=1}^{n} \mathbf{z}_k \mathbf{z}_k^{*T} \text{ and } \mathbf{Y} = \sum_{l=1}^{m} \mathbf{z}_l \mathbf{z}_l^{*T}, \tag{5}$$

where $\mathbf{z}_k$ refers to the complex vector of a pixel k in $r1$, while the complex vector of a pixel l in $r2$ is denoted by $\mathbf{z}_l$.

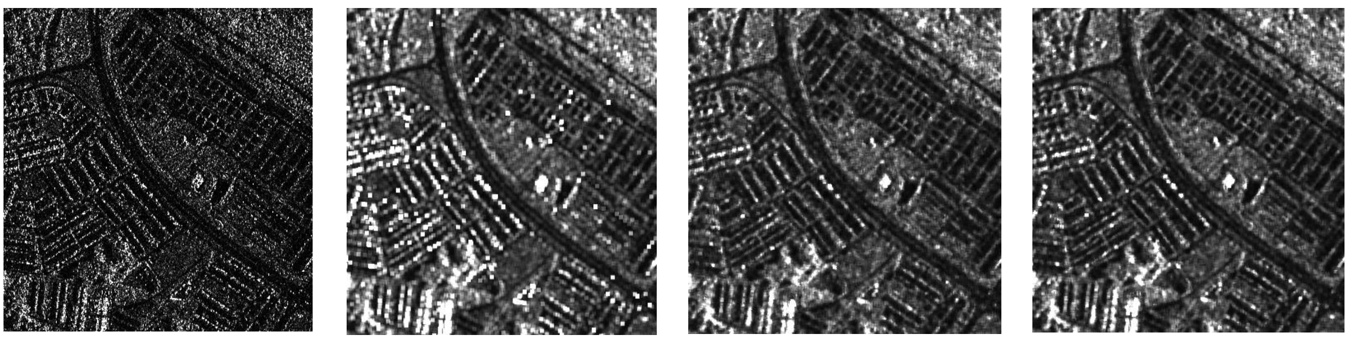
3) Compute the Wilks' lambda as given in (4). Its value is 0.25 for a perfectly homogeneous area with $\mathbf{X} = \mathbf{Y}$.

4) Mark the pixel i as an edge pixel if the following criteria are fulfilled:

$$\Lambda \le U_{1-\alpha/2} \text{ or } \Lambda > U_{\alpha/2}. \tag{6}$$

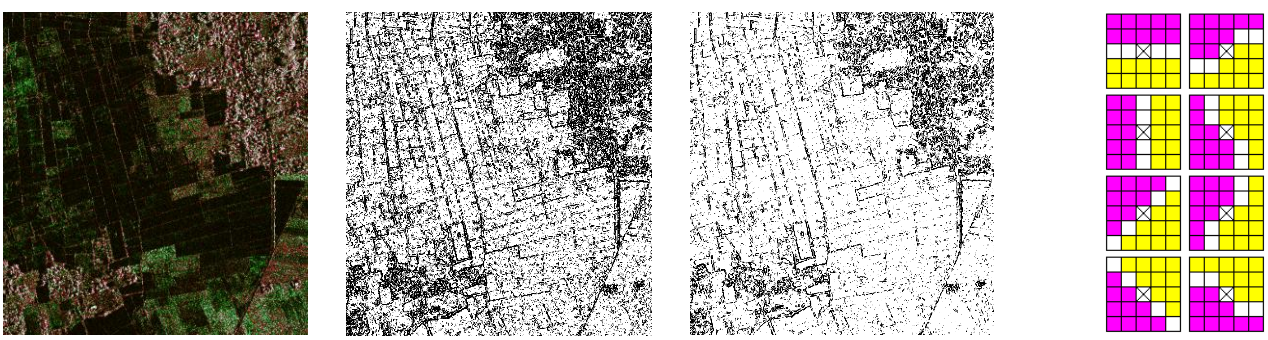
The notation U refers to the critical value with a desired significance level α. If the pixel is an edge pixel, go to Step 5. Otherwise, employ another edge template and repeat Steps 1–4.

5) Move the edge template to the next pixel and repeat Steps 1–4. Terminate the execution if there are no more pixels to be processed. Fig. 2 (b) and (c) show the edge detection outputs obtained separately with significance levels of 0.01 and 0.001.



(a) (b) (c) (d)

Fig. 1. Filtering results of TerraSAR-X HH intensity over a built-up area, where the filtering was performed using a 5×5 window. (a) Unfiltered HH intensity. (b) Boxcar filter, which computes the average dual-polarization matrix as filtering output using all pixels within the test window. (c) Proposed filter (α = 0.25). (d) Proposed filter (α = 0.05).



(a) (b) (c) (d)

Fig. 2. (a) TerraSAR-X image over a rice paddy field, where $|HH|^2$, $|VV|^2$ and $|HHVV^*|^2$ are displayed in the RGB color space. (b) and (c) are edge detection results by using a set of edge templates of 5×5 pixels with significance levels of 0.01 and 0.001, respectively. Note that the detected edge pixels are colored in black. (d) presents the edge templates of 5×5 pixels. The crossed pixel is the pixel under test. The two test regions $r1$ and $r2$ are in yellow and magenta colors, respectively.

REFERENCES

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