Multivariate Change Detection on High Resolution Monovariate SAR Image Using Linear Time-Frequency Analysis

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Motivations

Change detection between two multivariate images I and J:

\[ \{ I = [i_1, i_2, \ldots, i_K] \in \mathbb{C}^{p \times K} \}
\[ \{ J = [j_1, j_2, \ldots, j_K] \in \mathbb{C}^{p \times K} \}
\]

\[ \forall k, i_k \sim \mathcal{N}(0_p, C_i) \quad \text{and} \quad j_k \sim \mathcal{N}(0_p, C_j) \]

Detection Problem:

\[ \{ H_0 : C_i = C_j \}
\[ H_1 : C_i \neq C_j \]

Detector:

\[ \hat{\lambda}_{\text{GLRT}} = \sqrt{\frac{2R}{\left( \sum_{k=1}^{K} \left( \sum_{l=1}^{K} h_l \right)^2 \right)^2}} \]

Polarimetric (p=3) diversity is generally used but not available for monovariate images.

Idea: Use Spectro-Angular Diversity in High-Resolution SAR Images.

Spectro-Angular Diversity

In High-resolution Images, SAR pixels may be dispersive and anisotropic.

Construction Of Diversity

Traditional SAR reconstruction:

\[ I(\mathbf{r}) = \int_{D} H(\mathbf{k}) \exp\left(2\pi i k^T \mathbf{r}\right) d\mathbf{k} \]

With:

\[ \mathbf{r} \text{, pixel position} \]
\[ \mathbf{k} = [k_{\cos(\theta)}, k_{\sin(\theta)}]^T \text{, wave vector} \]
\[ H \text{, backscattering coefficient} \]
\[ \nu \text{, frequency and angular support of } H \]

Use of short time Fourier Transform:

\[ W_{lm}(\mathbf{r}) = \int_{0}^{2\pi} d\theta \int_{-\infty}^{\infty} d\mathbf{k} H(\mathbf{k}, \theta) \phi_{lm}(\mathbf{k}, \theta) e^{i\nu k^T \mathbf{r}} d\mathbf{k} \]

With:

\[ \phi_{lm}(\mathbf{k}, \theta) = \begin{cases} 1 & \text{if } (\mathbf{k}, \theta) \in \Delta_{lm} \\ 0 & \text{otherwise} \end{cases} \]

\[ \Delta_{lm} = \left[ [k_{\min}, k_{\max}] \cup [\theta_{\min}, \theta_{\max}] \right] \]

\[ k = k_{\max} - k_{\min} \]

\[ \kappa = \kappa_{\max} - \kappa_{\min} \]

\[ \Delta_{\theta,lm} = \left[ [0, \frac{(m-1)\pi}{N_{\theta}}] \cup \left[ \frac{m\pi}{N_{\theta}}, \frac{m\pi}{N_{\theta}} \right] \right] \]

For each pixel, we obtain a vector:

\[ i = [W_{11}(\mathbf{r}, \theta), W_{12}(\mathbf{r}, \theta), \ldots, W_{N_{\theta}N_{\nu}}(\mathbf{r}, \theta)]^T \]

Example with 3 Sub-Bands and 3 Sub-Looks:

Simulations and Results

Dataset: SANDIA National Labs High Resolution SAR Image with artificially embedded targets.

Test of detection at \( \text{Pfa}=10^{-3} \) with spectro-angular diversity (p=25, left) and without (p=1, right):

Performances estimation with Monte-Carlo Trials:

Conclusion

A new methodology for Change Detection using Spectro-Angular Diversity has been proposed. The performances were evaluated and proved to be better when using this diversity rather than working on the amplitude alone.