Polarimetric adaptive speckle filtering driven by temporal statistics for PSI applications

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Introduction

Persistent Scatterers Interferometry (PSI)

• Used to measure surface deformation evolution from SAR data

• Select for processing only good quality pixels:
  – Amplitude dispersion index → Persistent Scatterers (point-like, PS)
  – Average coherence → Coherent Pixels (distributed scatterers, DS)

• Urban environments: Mix of PS and DS
  – Estimation of DS parameters → speckle filtering
  – Speckle filtering → loss of PS information due to averaging

• How to process together PS and DS?
Speckle filtering:

• Boxcar (multi-look) or sliding window:
  – Suitable for homogeneous areas with fully developed speckle
  – Resolution loss $\rightarrow$ not suitable for PS analysis

• Spatial adaptive speckle filters:
  – Adapt to filter only homogeneous areas
  – Driven by spatial statistics $\rightarrow$ spatial estimation window (PS loss)

• Spatial adaptive filters driven by temporal information:
  – Driven by temporal statistics $\rightarrow$ no initial spatial estimation window
  – Homogeneous areas are filtered while PS are preserved
  – Require a sufficient number of SAR images
Introduction

[Ferretti’11] → DespecKS

- Two pixels are considered Statistically Homogeneous Pixels (SHP) based on a two-sample Kolmogorov-Smirnov test:
  - Compares p.d.f. of the pixel amplitudes.
  - P.d.f are estimated from multi-temporal data.
- Pixels with sufficient SHP neighbours are processed as DS.
- Pixels with few SHP neighbours are processed as PS.

Limitations:
- Only takes into account amplitude information
- Conceived for single-pol data
- Multi-channel p.d.f. estimation is not straightforward
Introduction

Objectives:

- Polarimetric, PS preserving adaptive filter approach
- Polarimetric PSI with joint processing of PS and DS

INCREASED MAP DENSITY AND ACCURACY
Algorithm

Algorithm steps:

• Find homogeneous areas: Polarimetric Homogeneity Test
• Discriminate PS and DS
• Polarimetric Optimization. Find polarimetric channel that:
  • Minimizes amplitude dispersion for each PS
  • Maximizes average interferometric coherence for each DS
• Select pixels with good quality $\rightarrow$ low $\sigma_\phi$
• Process using any PSI technique
Polarimetric Homogeneity Test

Target vector (Pauli basis):

\[ k = \frac{1}{\sqrt{2}} \begin{bmatrix} HH + VV \\ HH - VV \\ 2HV \end{bmatrix} \]

Coherency matrix:

\[ T = E[kk^\dagger] \rightarrow T = \frac{1}{L} \sum_{l=1}^{L} k_l \cdot k_l^\dagger \]

\[ k \sim \mathcal{N}_q^C(0, \Sigma) \rightarrow T \sim \mathcal{W}_q^C(L, \Sigma) \]

Temporal coherency matrix:

\[ T = \frac{1}{N} \sum_{n=1}^{N} k_n \cdot k_n^\dagger \quad \text{N images} \rightarrow \text{N independent samples} \]
Polarimetric Homogeneity Test

Equality test for Wishart distributed matrices

[Conradsen et al. 2003]:

• Hypothesis: $\Sigma_i = \Sigma_j$

• Test $\rightarrow$ Likelihood ratio: $\Lambda = \frac{|T_i|^{N_i} |T_j|^{N_j}}{|N_i T_i + N_j T_j|^{N_i+N_j}}$

• Equality condition:

$$\Lambda > c_\beta \quad P_{fa}(c_\beta) = P(\Lambda \leq c_\beta) = \beta$$

Hyphotesis confirmed $\rightarrow$ Polarimetrically Homogeneous Pixels (PHP)

• Pixels with more than $R$ PHP are treated as DS (filtered)

• Pixels with less than $R$ PHP are treated as PS (not filtered)
Polarimetric Homogeneity Test

Search window = 15 x 15
log Λ threshold = -20

Number of identified PHP
(Barcelona)
Polarimetric Homogeneity Test

Polarimetric adaptive speckle filter $\rightarrow R = 20$

Detail of Barcelona airport. HH+VV amplitude
PSI optimization review

General framework and formulation for vector interferometry
[Cloude and Papathanassiou, 1998]:

Projection:

\[
\mu = \omega^\dagger k
\]

Projection vector parameterization:

\[
\omega = \begin{bmatrix}
\cos(\alpha) \\
\sin(\alpha) \cos(\beta) e^{j\delta} \\
\sin(\alpha) \sin(\beta) e^{j\psi}
\end{bmatrix},
\]

ESPO: Exhaustive Search
Polarimetric Optimization

\[
\begin{align*}
0 \leq & \alpha \leq \pi/2 \\
0 \leq & \beta \leq \pi/2 \\
-\pi \leq & \delta < \pi \\
-\pi \leq & \psi < \pi
\end{align*}
\]
PSI optimization review

• Average coherence optimization:

Maximize:

\[
|\gamma| = \frac{1}{K} \sum_{k=1}^{K} |\gamma_k|, \quad \text{with } \gamma_k(\omega) = \frac{\omega^\dagger \Omega_{ij}\omega}{\sqrt{\omega^\dagger T_{ii} \omega} \sqrt{\omega^\dagger T_{jj} \omega}}
\]

Constraint:

\[
\Omega_{ij} = E[k_i k_j^\dagger]
\]

\[
T_{ii} = E[k_i k_i^\dagger]
\]

\[
T_{jj} = E[k_j k_j^\dagger]
\]

• Amplitude dispersion optimization:

Minimize:

\[
D_A = \frac{\sigma_a}{\bar{a}} = \frac{1}{|\omega^\dagger k| \sqrt{N - 1}} \sqrt{\sum_{i=1}^{N} \left( |\omega^\dagger k_i| - |\omega^\dagger k| \right)^2}
\]

Constraint: \(\omega_i = \omega_j = \omega \ \forall \ i, j \rightarrow \text{ESM}\)
Joint processing of DS and PS

• Common quality criterion $\rightarrow$ phase standard deviation $\sigma_\phi$

- Amplitude dispersion: $D_A \approx \sigma_\phi$ for low values of $D_A$ (high SNR)  
  [Ferretti et al., 2001]
Joint processing of DS and PS

- **Common quality criterion**
  - Phase standard deviation: $\sigma_\phi = \sqrt{\int \int _{\phi} (\phi - \phi_0)^2}$

$$\gamma \approx \frac{L_e}{(\text{azimuth factor} \times \text{range factor})}$$

$$\frac{\phi - \phi_0}{0} \left( \frac{L_e + 1/2}{\left( \phi - \phi_0 \right)} \right)$$
Results

Data set:
41 images of Murcia (Spain) Feb-09 to May-10

• TerraSAR-X dual-pol: HH, VV
• Mean incidence angle: 37.8°
• Resolution: 6.6m Az, 1.17m Rg
• Spacing: 2.44m Az, 0.91m Rg
• Ovs. factors: 2.7 Az, 1.28 Rg

R = HH, G = VV, B = HH-VV

Images provided by DLR under the framework of project GEO0389
Results

Data set:
31 images of Barcelona (Spain) Jan-10 to Feb-12

- RADARSAT-2 full-pol
- Mean incidence angle: 29º
- Resolution: 7.6m Az, 5.2m Rg
- Spacing: 5.1m Az, 4.7m Rg
- Ovs. factors: 1.49 Az, 1.11 Rg

Images provided by MDA under the framework of project SOAR EU 6779

R = HH-VV
G = 2HV
B = HH+VV
Results

*Murcia (TERRASAR-X, DP)*

$\sigma_\phi$ threshold = 0.25 ($\approx D_A 0.25$)

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<table>
<thead>
<tr>
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<td>HH</td>
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\[ \sigma_\phi \text{ threshold} = 0.25 \ (\approx D_A 0.25) \]

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## Results

**Barcelona (RADARSAT-2, QP)**

\[ \sigma_\phi \text{ threshold } = 0.25 \ (\approx D_A 0.25) \]

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Results

*Barcelona (RADARSAT-2, QP)*

$\sigma_\phi$ threshold = 0.25 ($\approx D_A 0.25$)

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Summary

• An adaptive speckle filtering approach has been presented:
  – Polarimetric
  – PS compatible

• Methodology for joint processing of PS and DS proposed

• Important increase of deformation maps density:
  ▪ TerraSAR-X dual-pol
    – 1.53 times increase w.r.t. ESPO optimized data
    – 3.50 times increase w.r.t. single-pol (HH)
  ▪ RADARSAT-2 full-pol
    – 1.35 times increase w.r.t. ESPO optimized data
    – 9.26 times increase w.r.t. single-pol (HH)
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