Enhancements for High Resolution SAR Persistent Scatterer Interferometry

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Motivation

- new possible goals and challenges in PSI with high-resolution SAR-Images
  - expected vast increase in number of PS-Candidates
  - different appearance of PSCs (connected lines, areas, L-structures)
Motivation

- new goals and challenges in PSIInSAR with high-resolution SAR-Images
  - expected vast increase in number of PS-Candidates
  - different appearance of PSCs (connected lines, areas, L-structures)

=> new potentials for object specific evaluation (buildings, bridges, etc.)
DLR-TUM PSI-Approach

- **data import**
- **InSAR processing**
- **D-InSAR processing**
  - estimation: combined est. + hypothesis tests
- **visualisation**
  - \( v(t, rg, az) \)
  - \( Dh(rg, az) \)
  - atmospheric delay
- **calibration**
- **PS detection**
  - blob detection
Part I – Detection

DEM

CEOS CD

data import

InSAR processing

D-InSAR processing

estimation combined est. + hypothesis tests

visualisation

v(t, rg, az)

Dh(rg, az)

atmospheric delay

calibration

PS detection

blob detection
blob model:
- 2D rectangular region as (undistorted) primitive + Noise (here: additive)
- convolution of primitive region with Gaussian kernels:
  => noise suppression
  => blurred region ( = “blob”)

mathematically:

\[
 f_r(x, y) = \begin{cases} 
 1 & \text{for } |x| \leq 1 \text{ and } |y| \leq w \\
 0 & \text{otherwise}
\end{cases}
\]

\[
 r_\sigma(x, y, l, w) = f_r(x, y) * g_\sigma = (G_\sigma(x + l) - G_\sigma(x - l)) \cdot (G_\sigma(y + w) - G_\sigma(y - w))
\]

with \( G_\sigma(x) = \int_{-\infty}^{x} e^{-\frac{t^2}{2\sigma^2}} dt \) and \( g_\sigma(x) = \frac{1}{\sqrt{2\pi\sigma}} e^{-\frac{x^2}{2\sigma^2}} \)

(assuming noise is suppressed by low-pass filtering)
blob detection:
- initialize by setting parameters for length \( l \), width \( w \)
- find orientation of major axis by eigenvector analysis of Hessian matrix \( H \)
- detect center point by curvature maximum in direction of minor and major axis
- reconstruct blob boundary polygon and fit ellipse
- calculate geometric and radiometric features

Initialization:
\[
\sigma_w = \frac{w}{\sqrt{3}}, \quad \sigma_1 = \frac{1}{\sqrt{3}}
\]

**Hessian matrix** containing second derivatives for smaller scale \( \sigma_w \):
\[
H(x, y) = \begin{bmatrix}
r_{xx} & r_{xy} \\
r_{xy} & r_{yy}
\end{bmatrix}
\]
blob detection:
- initialize by setting parameters for length $l$, width $w$
- find orientation of major axis by eigenvector analysis of Hessian matrix $H$
- detect center point by curvature maximum in direction of minor and major axis
- reconstruct blob boundary polygon and fit ellipse
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$=>$ eigenvectors $e_1$, $e_2$ of Hessian matrix determine blob orientation

$=>$ determine curvature maximum along blob orientation (smaller eigenvalue $e_2$)
- convolution with second derivative of Gaussian Kernel of larger scale $\sigma_l$
- subpixel determination of maximum

\[
g_{\sigma_1}''(x) = \frac{x^2 - \sigma_1^2}{\sqrt{2\pi}\sigma_1^5} e^{-\frac{x^2}{2\sigma_1^2}}
\]
Blob Detection

- blob detection:
  - initialize by setting parameters for length l, width w
  - find orientation of major axis by eigenvector analysis of Hessian matrix H
  - detect center point by curvature maximum in direction of minor and major axis
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2D curvature maxima

Eigenvectors of Hessian matrix
 blob detection:
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Example: Large blobs
superimposed on smoothed image
superimposed on original image
blob detection:
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- find orientation of major axis by eigenvector analysis of Hessian matrix H
- detect center point by curvature maximum in direction of minor and major axis
- reconstruct blob boundary polygon and fit ellipse
- calculate geometric and radiometric features

Example: Blob chain

superimposed on smoothed image  superimposed on original image
Part II – Estimation

- data import
- InSAR processing
- D-InSAR processing
- estimation
  combined est. + hypothesis tests
- visualisation
  v(t, rg, az)
  Dh(rg,az)
  atmospheric delay
- calibration
- PS detection
  blob detection
Estimation Process

- restricted Least-Squares Adjustment: **points on a rigid line**

\[
\Delta \hat{x} = -(A'(BQ_{bb}B')^{-1} A)^{-1} A'(BQ_{bb}B')^{-1} w
\]

- weighting of arcs
- restrictions
- system matrix

unknowns in general (each PS): v, h

3 unknowns of group: v, h, v_x
Models for Displacement

- analysis for **single** buildings
- same displacement
  - differences always zero between points in group or
  - constant between each point in group and one reference point outside
- shearing or rotation
  - movement proportional to distance between points in line

\[
\Delta v_{mn} = \Delta v_m + v_x \Delta s_{ln}
\]

\[
v_{m} = \text{const}
\]

\[
v_{1,n} = \text{const}
\]
estimate displacement between reference point and each point in group
  ‣ estimation set up by maximizing ensemble coherence (periodogram)
  ‣ estimate first arc (use best point in group)

use as a priori knowledge for following estimations:
  ‣ variation of differences in height-estimations
    ‣ very small as PSCs on same level (e.g. roof)
    ‣ form defined (known) path as on certain structure (e.g. arch bridge, front of skyscraper)
  ‣ variation of differences in displacement
    ‣ constant while moving together
    ‣ linear increasing, dependent on distance between points

combine estimations for gain in accuracy
  ‣ standard deviation enhanced by least squares adjustment
  ‣ removement of outliers (hypothesis tests)
results for constant and linear increasing displacement (simulation)

20 arcs, 40° noise, **constant** displacement
increase: 0.00178 mm/y per m  \( \sigma = 0.0088 \)
displacement: -3.95 mm/y  \( \sigma = 0.037 \)
real: -4 mm/y

20 arcs, 40° noise, **linear increase** 0.5mm/y per m
increase: 0.5004 mm/y per m  \( \sigma = 0.0104 \)
displacement: -3.71 mm/y  \( \sigma = 0.062 \)
real: -4 mm/y
Comparison

- results of different noise level and number of arcs

<table>
<thead>
<tr>
<th>noise</th>
<th>unknowns</th>
<th>10 points</th>
<th>20 points</th>
<th>10 points</th>
<th>20 points</th>
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<tbody>
<tr>
<td></td>
<td>est. value</td>
<td>σ</td>
<td>est. value</td>
<td>σ</td>
<td></td>
</tr>
<tr>
<td>30°</td>
<td>increase mm/y per meter</td>
<td>-0.020</td>
<td>0.027</td>
<td>0.005</td>
<td>0.007</td>
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<tr>
<td></td>
<td>basic displacement</td>
<td>-3.938</td>
<td>0.044</td>
<td>-3.966</td>
<td>0.029</td>
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<tr>
<td>40°</td>
<td>increase mm/y per meter</td>
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<td>0.031</td>
<td>0.002</td>
<td>0.009</td>
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<tr>
<td></td>
<td>basic displacement</td>
<td>-3.921</td>
<td>0.050</td>
<td>-3.949</td>
<td>0.037</td>
</tr>
</tbody>
</table>

constant displacement for all points of group
Conclusion

- **blob detection**
  - different scales for length and width => not only circular but elliptical blobs
  - easy parameterization
  - fast and sub-pixel precise detection
  - accurate measurement of boundary

- **combined estimation**
  - increased accuracy of displacement of points in the same group (relative to reference point):
    \[ \sigma_{\text{LSA}}^2 \leq \frac{1}{n} \sigma_{\text{single}}^2 \]
  - provides support for monitoring single objects (e.g. bridges, large(er) buildings)
  - detection of possible risks / evidence for buildings caused by non-equal subsidence of points in group
Outlook

- upcoming tests, improvements

- blob detection:
  - integration in processing chain
  - exploitation of temporal features (geometric and radiometric coherence)
  - behaviour of detected blobs to phase stability

- combined estimation
  - classification to groups (same object)
  - use additional information from land register maps, GIS or Laser-DEM
  - integration of results in whole estimation process of all PSCs
Thank you for your attention!