Spectral-peak and complex-valued neural-network fileters: Filters to remove singular points for high-quality digital elevation model generation

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Outline

1. Introduction: Interferometric SAR (InSAR)
2. Filters in InSAR (conventional)
   1. Goldstein-Werner filter
   2. CMRF filter
3. Proposals
   1. Spectrum-peak filter (Speak filter)
   2. Complex-Valued Neural Network (CVNN) filter
4. Experiments and results
5. Summary
1 Interferometric Synthetic Aperture Radar (InSAR)

\[
\Delta H = \frac{\lambda R_m \sin \theta}{4\pi B_{CT} \cos(\theta - \gamma_{CT})} \Delta \Phi
\]

- Interferogram
- Digital Elevation Model (DEM)
- Phase Unwrapping
1 Singular point (SP)

Pixels near a SP are distorted.

\[ R(x, y) = \oint_C \nabla \phi(x, y) ds' \]

Phase Unwrapping

Artifact (cliff)
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2.1. Goldstein-Werner filter

• Is widely used spectrum-domain filter
• Modifies the spectrum $Z(u,v)$ to enhance the dominant components

$$H(u, v) = |Z(u, v)|^\alpha \cdot Z(u, v) \quad (\alpha < 1)$$

$$Z(u, v) = \frac{1}{N} \sum_{x=0}^{N-1} \sum_{y=0}^{N-1} z(x, y) \exp\{-j2\pi(ux + vy)/N\}$$

• Has Trade-off between SP-removal performance and DEM accuracy

(→ introduces another distortion?)

2.2. CMRF filter

- Based on complex-valued Markov random field (CMRF) model
- Compensate "singular unit" linearly in real space
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2.3. Basic ideas and proposals

GW filter idea
→ Amplitude values of dominant components should not be changed. Spectral peak filter (Speak filter)

+ CMRF filter idea
→ Use of correlation, generalization ability of neural networks and nonlinearity will enhance the compensation performance. Complex-valued neural network filter (CVNN filter)
3.1. Spectrum-peak(Speak) filter

- Leave peaks unchanged.
- Delete other power.
3.2. Complex-Valued Neural Network (CVNN)

\[ u_{lj} \equiv \sum_i w_{lj} i z_{(l-1)i} \]

\[ z_{lj} = f_{ap}(u_{lj}) = \tanh(|u_{lj}|) e^{j \arg(u_{lj})} \]

Keypoints:
1. Nonlinear filtering
2. Meaningful Generalization ability in complex domain

Hirose, *Complex-Valued Neural Networks, 2nd Ed.*, Springer 2012
Hirose, Yoshida, IEEE TNNLS
3.2 Correlation learning in CVNN filter

- Learning in non-SU area in Fourier domain
- To obtain correlation among pixels in Fourier domain based on 8-direction shifted window data.
3.2 Forward process in CVNN filter

- Use the neural network to SU window for distortion removal
- We estimate the spectrum, transform it to obtain real-space SU pixels, and replace them.
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4 Raw interferogram

#SP = 2217
4 GW filter

#SP = 393
4 Speak filter

#SP = 242
4 CVNN filter

#SP = 91
4.4.1. DEM – GW filter

(b) GW filter

(a) Ground truth
4.4.2. DEM – CMRF filter

(c)CMRF filter

(a)Ground truth
4.4.3. DEM – Speak filter

(d) Speak filter

(b) Ground truth
4.4.5. DEM – CVNN filter

(e) CVNN filter

(b) Ground truth

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# 4 Mean square error (MSE) & Peak-error square error (PSE)

<table>
<thead>
<tr>
<th>Method</th>
<th>Number of SPs</th>
<th>MSE [m$^2$]</th>
<th>MSNR [dB]</th>
<th>PSE [m$^2$]</th>
<th>PSNR [dB]</th>
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<tbody>
<tr>
<td>GW filter</td>
<td>393</td>
<td>457</td>
<td>34.65</td>
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<td>CMRF filter</td>
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<td>Speak filter</td>
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<td>35.37</td>
<td>48370</td>
<td>14.40</td>
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<td>CVNN filter</td>
<td>91</td>
<td>377</td>
<td>35.48</td>
<td>33120</td>
<td>16.05</td>
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</tbody>
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- We proposed two distortion-removing adaptive filters working nonlinearly in Fourier domain, resulting in better performance.
- Speak filter (spectrum peak filter) has low calculation cost, but showed good performance.
- CVNN filter presented highest performance by utilizing the correlation in spectral domain as well as the high generalization ability of CVNN in complex domain.