InSAR Microsatellite Constellations Enabled by Formation Flying and Onboard Processing Capabilities

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Interferometric Synthetic Aperture Radar (InSAR)

- Augment existing SAR mission with constellation of receive-only microsatellites
- Low-cost addition of interferometric capabilities

Is this possible with CanX technology?

- SAR Interferometry requires baseline knowledge and maintenance
- Limited microsatellite downlink/power: extract data of interest onboard
- On-board image processing requires position and attitude knowledge
CanX Mission Enabling Technologies

• SFL Generic Nanosatellite Bus
  – 20cm cube, 7kg, 30% payload volume

• CanX-4 & 5: Formation flight in 2012
  – Formation flying control algorithms
  – Canadian Nanosatellite Advanced Propulsion System (CNAPS)
  – Commercial GPS
    • Absolute position/velocity: 2-5 m, 5-10 cm/s
    • Relative position/velocity: 2-5 cm, 1-3 cm/s
  – 3-axis ADCS

• CanX-3 (BRITE): Stellar photometry in 2011
  – Nanosatellite star tracker
    • Arcminute accuracy (limited by roll axis)
    • 7-arcsecond accuracy (dual orthogonal star trackers)
Interferometric SAR

Receive-only microsatellites

SAR transmitter

$R$

$R + dR$

baseline

orbit
Onboard Image Alignment

Challenges:

- Platform position/attitude can be used to geographically locate image (georeferencing)
  - Depends on accuracy of microsatellite GPS/ADS
- Automatic registration based on image content
  - Computationally intensive, complicated by SAR image characteristics

The accuracy of our georeferencing determines the complexity of our registration algorithm
Georeferencing

\[ r_i^m = r_b^m(t) + R_b^m(t) \, r_i^b(t) \]

Find geographic location of pixel \( i \), imaged at time \( t \)

- \([r_i^m]\) - image pixel \( i \) in the mapping frame
- \([r_b^m(t)]\) - location of imager at time \( t \) in the mapping frame
- \([R_b^m(t)]\) - rotation matrix between the body and mapping frame at time \( t \)
- \([r_i^b(t)]\) - vector from the imager to pixel \( i \) in the body frame at time \( t \)
Georeferencing

\[
\mathbf{r}_i^m = \mathbf{r}_b^m(t) + \mathbf{R}_b^m(t) \mathbf{r}_i^b(t)
\]

\[
\mathbf{r}_i^b = \begin{bmatrix}
    s_x x_i \\
    s_y y_i + z \tan \theta \\
    -Z
\end{bmatrix}
\]

\[
s_x = \frac{s_x^2}{c^2} \\
s_y = \frac{s_y^2}{2BV}
\]

\[(x_i, y_i, z)\] is the location of an image pixel (fixed to terrain height)

\[\theta\] is the incidence angle

\[s_x\] range resolution depends on signal bandwidth \(B\)

\[s_y\] azimuth resolution depends on range, platform velocity, and imaging time \((R, V, T)\)
Measurement Errors

• Perturb position, attitude measurements using CanX sensor accuracies
  – 5m GPS absolute position accuracy
  – 7 arcsecond attitude accuracy (dual orthogonal star trackers)

• Translations and rotation: *rigid transformation*

<table>
<thead>
<tr>
<th>5m GPS, 7-arcsec ADS</th>
<th>10m GPS, 7-arcsec ADS</th>
<th>5m GPS, 1-arcsec ADS</th>
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</tbody>
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Automatic Registration

Phase Correlation Method

- Two images differ by displacement (translation)
- Cross power spectrum
  - Peak of the inverse located at coordinates equal to image displacement
- Log-polar transformation:
  - Rotation and scale reduce to translation
  - Iteration with translation recovery to find correct peak
- Global method, rigid transformations
- Well-suited for onboard processing; fast!

Peak at image offset (10,10)
Phase Correlation Results

- Image pair offset by translation
- Added 10-deg rotation
- Temporal changes visible (3 weeks between passes)
Conclusions

• CanX capabilities enable future formation flight missions: multistatic InSAR microsatellite receivers

• Baseline determination and maintenance
  – Interferometric applications dictate formation baseline requirements
    • CanX-4&5 formation flying control algorithms
    • Canadian Nanosatellite Advanced Propulsion System (CNAPS)
    • GPS relative position/velocity

• Onboard image processing (downlink only data of interest)
  – Position/attitude knowledge reduce complexity of image registration problem
    • CanX-4&5 GPS absolute position
    • CanX-3 (BRITE) star tracker
  – Error propagation demonstrates that registration problem is limited to rigid transformations
  – Phase correlation method suitable for onboard implementation, demonstrated on SAR imagery