Robust Automated Residual Motion Correction for Repeat Pass SAR

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Outline

• Introduction to residual motion errors
• Mitigation strategy
• Measurement noise
• Improving robustness
Residual Motion Errors

- Airborne SAR trajectories deviate significantly from desired flight path.
  - Requires topography- and aperture-dependent motion compensation.

![Graph showing deviation over along track position](image-url)
Residual Motion Errors

- Even with perfect motion compensation algorithms, limits of motion measurement accuracy present enormous challenges for exploitation of SAR phase
  - Post-processed GPS/INU position accuracy on the order of 5 cm
  - L-Band SAR wavelength of about 25 cm

Note: Corner position also subject to measurement error.
Residual Motion Errors

Phase artifacts due to residual motion

Range

Azimuth

-\pi \leq \text{phase} \leq \pi
Residual Motion Correction

- Need a way to estimate motion errors from the data itself!
- Consider a simplified model
  - Linear motion
  - Linear motion error
Residual Motion Correction

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\[
\Delta x \approx \rho \frac{dr}{dx}
\]

Azimuth

Motion Error

Range

Target

Image Offset

Radar
Residual Motion Correction

• Linear part of position error shifts the SAR impulse response
  – Scaled by range, so small slopes (e.g., 1 cm per km) mean big offsets

• More complicated model used for UAVSAR
  – Range variation of squint and look angles
  – Electronically steered antenna

\[ \Delta s = \left[ \frac{\sin \alpha \langle \hat{b}, \hat{l} \rangle - \langle \hat{b}, M \hat{n} \rangle + \rho \hat{l}_c \frac{\partial b_c}{\partial s} + \rho \hat{l}_h \frac{\partial b_h}{\partial s}}{\langle \hat{v}, \hat{n} \rangle - \sin \alpha \langle \hat{v}, \hat{l} \rangle} \right] \langle \hat{v}, \hat{s} \rangle \]

• Flavor is the same: slope of residual motion shifts the targets
• Strategy: Measure shifts and invert the model

Hensley et al, "Residual Motion Estimation for UAVSAR," 2009 IEEE Radar Conference
• Method requires measurement of geometric shifts.

• Obtain the measurement by incoherent cross-correlation of the images comprising the InSAR pair
  – Relative offset, so can only solve for relative motion

• Quality of motion estimates and InSAR products very sensitive to offset measurements

• Quality of offset measurement highly variable!
  – Cross-correlation accuracy naturally depends strongly on image coherence.

• Need a way mitigate impact of bad offset measurements
Low Coherence

3 pixels
Improving Robustness

• Simplest mitigation strategy is to mask data based on coherence threshold
  – Alternatively use estimated offset variance, closely related to coherence.

• Choice of threshold extremely important to residual motion estimation
  – Too low could pass too much noise
  – Too high could pass too little signal

• Challenging in a high-throughput environment
  – Limited \textit{a priori} knowledge of scene statistics
  – Frequently requires hand-tuning for best results
Improving Robustness

No “one size fits all” threshold!
Improving Robustness

• Should try to exploit the available data to infer an appropriate threshold.

• Heavy tails of offset distributions suggest a statistical approach

• Try a two-component (“good” and “bad”) mixed-normal model of the cumulative distribution function

\[ y(x) = (1 - \beta) \phi(x, \mu_g, \sigma_g) + \beta \phi(x, \mu_b, \sigma_b) \]

\[ \phi(x, \mu, \sigma) = \frac{1}{2} \left[ 1 + \text{erf} \left( \frac{x - \mu}{\sigma \sqrt{2}} \right) \right] \]

x is the offset
y is the offset CDF, estimated by sorting the data
\( \beta \) is the fraction of “bad” data
\( \mu \) is the mean
\( \sigma \) is the standard deviation

• Use the estimate of the amount of the “bad” component to pick the threshold
Improving Robustness

Offset [pixels]

Probability Density

Data
Good part
Bad part
Improving Robustness

• Resulting thresholds prove satisfactory for a wide variety of scene types

• Eliminates need for time-consuming hand tuning of thresholds

Dark blue denotes culled data
Residual Motion Correction
• Questions / comments?