Scripps Institution of Oceanography Technical Report

GMTSAR: An InSAR Processing System Based on Generic Mapping Tools

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HW2

1) Describe an algorithm to transform a point on the surface of the earth (longitude, latitude, elevation) into radar coordinates.

2) When a SAR image is focussed at zero Doppler, the radar coordinates of a point reflector correspond to the minimum range. Why?

3) Most SAR instruments emit a frequency modulated chirp rather than a short pulse. Why?

4) Make a plot of the real and imaginary parts of the function given in (B5) for a time interval of -2 to 2 seconds. Use $R_o = 850 \, km$, $\dot{R}_o = 0$, $\ddot{R}_o = \frac{V^2}{R_o}$ where $V = 7125 \, ms^{-1}$. 
HW3

1) Give two reasons why the critical baseline for ALOS is more than 10 times longer than for ERS.

2) What happens to the phase of an interferogram in areas where the slope of the topography facing the radar exceeds the incidence angle of the radar?

3) Explain the terminology, master and slaves, reference and repeat.

4) Derive equation (C8)
Table of Contents:

1. Introduction
   1.1 Objectives and limitations of GMTSAR
   1.2 Algorithms: SAR, InSAR and the need for precise orbits
      1.2.1 Proper focus
      1.2.2 Transformation from geographic to radar coordinates
      1.2.3 Image alignment
      1.2.4 Flattening interferogram - no trend removal

2. Software
   2.1 Standard products
   2.2 Software design

3. Processing Examples
   3.1 Two-pass processing
   3.2 Stacking and time series
   3.3 ScanSAR Interferometry

4. References

5. Problems

Appendix A. Principles of Synthetic Aperture Radar
Appendix B. SAR Image Formation
Appendix C. InSAR
Appendix D. ScanSAR processor and interferometry
Appendix E. Geolocation accuracy for Pinon corner reflectors
Appendix F. Installation of GMTSAR
forming interferogram

\[ C(\mathbf{x}) = A(\mathbf{x})e^{i\phi(\mathbf{x})} \]  

where \( \mathbf{x} = (\rho, a) \) is the position vector consisting of range \( \rho \) and azimuth \( a \). Their product is

\[ C_2C_1^* = A_1A_2e^{i(\phi_2 - \phi_1)} = R(\mathbf{x}) + il(\mathbf{x}). \]  

The phase of the interferogram is extracted in the usual way.

\[ (\phi_2 - \phi_1) = \tan^{-1}\left(\frac{I}{R}\right) \]
phase =
  earth curvature (almost a plane, known) +
  topographic phase (broad spectrum) +
  surface deformation (broad spectrum, unknown) +
  orbit error (almost a plane, largely known) +
  ionosphere delay (a plane or 40-km wavelength waves) +
  troposphere delay (power law, unknown) +
  phase noise (white spectrum, unknown)
\[(\rho + \delta \rho)^2 = \rho^2 + B^2 - 2\rho B \sin(\theta - \alpha)\] (C7)

Next we make two standard approximations that are useful for introducing interferometric concepts but are unnecessary and also lead to inaccurate results. First we assume $\delta \rho \ll \rho$ so we have

\[\delta \rho = \frac{B^2}{2\rho} - B \sin(\theta - \alpha) .\]  (C8)

Furthermore since $B \ll \rho$ the parallel ray approximation yields.

\[\phi = \frac{-4\pi}{\lambda} B \sin(\theta - \alpha)\] (C9)

The phase difference depends on the parallel component of the baseline. The derivative of the phase with respect to range is

\[\frac{\partial \phi}{\partial \rho} = \frac{-4\pi}{\lambda} B \cos(\theta - \alpha) \frac{\partial \theta}{\partial \rho}\] (C10)
Perpendicular baseline MATTERS!

\[ B_\parallel = B \sin(\theta - \alpha) \]

\[ B_\perp = B \cos(\theta - \alpha) \]

\[ \frac{\partial \phi}{\partial \rho} = \frac{-4\pi B \cos(\theta - \alpha)}{\lambda \rho \sin \theta} \left( \cos \theta - \frac{\rho}{b} \right) \]

\[ (\phi - \phi_e) \equiv \frac{-4\pi r_e B \cos(\theta - \alpha)}{\lambda \rho b \sin \theta} (r - r_e) \]

phase due to curved earth

phase due to topography
3) This is an interferogram made from ERS SAR data. One fringe represents $2\pi$ phase change between the reference and repeat SAR acquisition. Count the fringes across the image and calculate the perpendicular baseline. You will need the look angle from the previous problem. The total change in slant range across the image is 50 km. Why does the fringe rate vary slightly across the image?
Phase from curved Earth

Figure C3 Triangle formed by the range $\rho$, radius of the earth $r_e$ and spacecraft height $b$.

Using the Law of cosines one finds

$$\eta = \cos \theta = \frac{\left( b^2 + r_e^2 - \rho^2 \right)}{2\rho b}$$

(C12)

$$\frac{\partial \phi}{\partial \rho} = -\frac{4\pi B}{\lambda \rho} \frac{\cos(\theta - \alpha)}{\sin \theta} \left( \cos \theta - \frac{\rho}{b} \right)$$

(C)
3) This is an interferogram made from ERS SAR data. One fringe represents $2\pi$ phase change between the reference and repeat SAR acquisition. Count the fringes across the image and calculate the perpendicular baseline. You will need the look angle from the previous problem. The total change in slant range across the image is 50 km. Why does the fringe rate vary slightly across the image?
Critical Baseline

\[ \frac{\partial \phi}{\partial \rho} = \frac{-4\pi B_\perp}{\lambda \rho} \frac{\cos \theta}{\sin \theta} < \frac{2\pi}{\Delta \rho} \]

\[ B_c = \frac{\lambda \rho}{C\tau} \tan \theta \]  \hspace{1cm} (C16)

For the parameters of the ERS satellite the critical baseline is 1100 m (Table 1). For topographic recovery, a baseline of about 1/4 critical is optimal. Of course for change detection, a zero baseline is optimal but not usually available.

**Table 1. Comparison of critical baseline**

<table>
<thead>
<tr>
<th>Look angle</th>
<th>23°</th>
<th>34°</th>
<th>41°</th>
</tr>
</thead>
<tbody>
<tr>
<td>ERS/ENVISAT 16 MHz</td>
<td>1.1 km</td>
<td>2.0</td>
<td>2.9</td>
</tr>
<tr>
<td>ALOS FBD 14 MHz</td>
<td>3.6</td>
<td>6.5</td>
<td>9.6</td>
</tr>
<tr>
<td>ALOS FBS 28 MHz</td>
<td>7.3</td>
<td>13.1</td>
<td>18.6</td>
</tr>
</tbody>
</table>

ERS/ENVISAT - altitude = 790 km, wavelength = 56 mm
ALOS - altitude = 700 km, wavelength = 236 mm
Shaded area is most common mode for interferometry.
Phase from topography

\[ \frac{\partial \phi}{\partial r}(r_e) = -\frac{4\pi r_e}{\lambda \rho b} \frac{B \cos(\theta_e - \alpha)}{\sin \theta_e} \]

where \( \theta_e \) is the look angle to the spheroid (C12).

Into elevation as a function of range is

\[ (r - r_e) = -\frac{\lambda \rho b}{4\pi r_e} \frac{\sin \theta_e}{B \cos(\theta_e - \alpha)}(\phi - \phi_e) \]

\[ h = \frac{\lambda \rho \sin \theta_e}{2B_\perp} \]  \hspace{1cm} (C21)

For the case of ERS with a perpendicular baseline of 100 m, this altitude of ambiguity is about 90 m. For change detection, a higher number is better.
4) Interferogram with fringes due to geometry and Earth curvature removed. What are the cause(s) of the residual fringes? Why is the phase along the shoreline of the Salton Sea not exactly constant? (there are several possibilities).
How high is Toro Peak?

5) This is a zoom of the previous interferogram. Estimate the height difference between Toro Peak and the Salton Sea. Identify areas of layover?
deformation and topography
Triggered slip on Southern San Andreas Fault
Need for Precise Orbits

1. proper focus
2. transform from geographic radar coordinates
3. image alignment
4. flattening interferogram

Brute force algorithm given precise orbit subroutine

   pick target point
   fly satellite along orbit and identify point of closest approach

(This is inefficient but computers are fast so don’t waste time coding.)
Batch processing for time series
L-band vs. C-band

improved coherence
[Rosen et al., JGR, 1996]

lower fringe rate = lower range precision?, easier phase unwrapping

ionospheric delay 16x worse at L-band
X-band
3 cm
TerraSAR

**COSMO-SkyMed** interferogram using data from 19 February 2009 and 9 April 2009. Perpendicular baseline is 480 m, and the satellite’s right-looking angle is 37 degrees. The large green square represents the Mw 6.3 main shock, smaller green squares represent the Mw > 5 aftershocks, the yellow line marks the observed co-seismic surface breaks and the black triangles represent GPS stations used for SAR validation.

http://www.esa.int/esaEO/SEM4PJ9NJTF_index_1.htm
Envisat interferogram interpretation by Italy’s Istituto Nazionale di Geofisica e Vulcanologia (INGV). The large green square represents the Mw 6.3 main shock, the smaller green squares represent the Mw > 5 aftershocks and the black triangles represent GPS stations used for SAR validation. The yellow line east of L’Aquila shows the location of a ~4 km-long alignment of co-seismic surface breaks observed in the field by INGV researchers. This alignment corresponds to a northwest-southeast strip where the spatial fringe rate seems to exceed the limit for interferometric correlation. This may indicate that the fault dislocation reached, or was very close to, the surface along this line. The observed pattern of ground displacement is in very good agreement with the earthquake source mechanism (the ‘beach ball’), confirming that the earthquake source is a normal fault striking 144 degrees (clockwise from north), and dipping to the southwest.

http://www.esa.int/esaEO/SEM4PJ9NJTF_index_1.html
On April 6, 2009 (UTC), magnitude 6.3 earthquake occurred in central Italy. The Japan Aerospace Exploration Agency (JAXA) performed an emergency observation on April 22, 2009 using the Phased Array Type L-band Synthetic Aperture Radar (PALSAR) installed on the Advanced Land Observing Satellite (ALOS) to determine the state of damage caused by the earthquakes. In this report, we conducted differential interferometric SAR (DInSAR) analysis to detect crustal deformation using the data acquired on April 22, 2009 and July 20, 2008

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