Image Cross-Correlation Using COSI-Corr: A Versatile Technique to Monitor and Quantify Surface Deformation in Space and Time

Sébastien Leprince, François Ayoub, and Jean-Philippe Avouac

California Institute of Technology

December 9, 2011

AGU 2011, Invited
COSI-Corr: Co-registration of Optically Sensed Images and Correlation

**Inputs:**
- Raw images
- Orbits, platform attitudes, camera model
- Digital Elevation Model

**Orthorectification:**
Images must superimpose accurately

**Correlation:**
- Sub-pixel Correlation

**Outputs:**
- N/S offset field
- E/W offset field
- SNR

Displacement in rows and columns provide the E/W and N/S components of the ground deformation

The Signal to Noise Ratio assesses the measure quality.

Leprince et al., 2007 - http://www.tectonics.caltech.edu/slip_history/spot_coseis/
Comparing images acquired from different viewpoints

Can you find the moving piece?
Comparing images acquired from different viewpoints

Images must be projected and resampled in a common geometry to be compared.
Image Resampling: principle

Use approximated sinc kernels to preserve subpixel information and limit aliasing.
Sub-Pixel Image Correlation: local rigid translations

- Fourier Shift Theorem

\[ i_2(x, y) = i_1(x - \Delta_x, y - \Delta_y) \]
\[ I_2(\omega_x, \omega_y) = I_1(\omega_x, \omega_y) e^{-j(\omega_x \Delta_x + \omega_y \Delta_y)} \]

- Normalized Cross-spectrum

\[ C_{i_1i_2}(\omega_x, \omega_y) = \frac{I_1(\omega_x, \omega_y) I_2^*(\omega_x, \omega_y)}{|I_1(\omega_x, \omega_y) I_2^*(\omega_x, \omega_y)|} = e^{j(\omega_x \Delta_x + \omega_y \Delta_y)} \]

- Finding the relative displacement

\[ \phi(\Delta_x, \Delta_y) = \sum_{\omega_x=-\pi}^{\pi} \sum_{\omega_y=-\pi}^{\pi} W(\omega_x, \omega_y) |C_{i_1i_2}(\omega_x, \omega_y) - e^{j(\omega_x \Delta_x + \omega_y \Delta_y)}|^2 \]

\[ W \text{ weighting matrix. } (\Delta_x, \Delta_y) \text{ such that } \phi \text{ minimum.} \]

S. Leprince et al., IEEE TGRS, 2007
Retrieving horizontal deformation: using SPOT imagery

SPOT 5 images
2.5 m resolution

2009-05-26
2010-04-08

SPOT images provided via USGS:
Rich Briggs
Ken Hudnut

USGS
science for a changing world
2010 Mw 7.2 El Mayor Earthquake - SPOT Imagery

Can you see the ground motion?
Can you see the ground motion?
The 2010 Mw 7.2 El Mayor-Cucapah Earthquake: Horizontal offsets from SPOT imagery

We measure slip variations for both lateral and normal components. Accuracy better than 1/10 pixel.

Wei et al., Nature Geoscience, July 2011
Iceland Krafla crisis 1975-1984: declassified spy images
Iceland Krafla crisis 1975-1984: declassified spy images

- Corona-Hexagon KH-9 correlated with SPOT images
- High resolution archived air-photos

Study by J. Hollingsworth, Caltech
Tracking Sand Dunes on Mars, Nili Patera

Sand ripples displacement over 3 months retrieved from NASA HiRISE instrument orbiting Mars

Study by F. Ayoub, Caltech
Taking Advantage of Panchromatic and Multi-Spectral Pushbroom Sensors

Time delay between Pan and MSI acquisition is around 2.5-3 s on SPOT satellites
Taking Advantage of Panchromatic and Multi-Spectral Pushbroom Sensors

Correlating panchromatic and green bands to derive oceanic wave velocity
Taking Advantage of Panchromatic and Multi-Spectral Pusbroom Sensors

Study with Marcello De Michele, BRGM, France. In press RSE, 2011.
Retrieving vertical offset from pre- post-LiDAR differencing

\[
\begin{align*}
h_2(x) - h_1(x) &= h_1'(x)dx + dz \\
h_2(x - dx) - h_1(x) &= dz
\end{align*}
\]

We use COSI-Corr to estimate and compensate the horizontal displacement between pre- and post-EQ LiDAR
Vertical offsets: Borrego and Puerta Accommodation Fault zones

- LiDAR differencing before and after horizontal compensation

with S. Akciz, K. W. Hudnut, A. Hinojosa Corona, and J. M. Fletcher
Crack Experiments in the Lab: Earthquake Simulations

Work with Vito Rubino and Ares Rosakis, Caltech
Conclusions:

- **Sub-pixel** image registration and correlation are versatile tools to monitor time changes,

- **High resolution, high accuracy offset maps** in 2D or 3D, ideally 4D with time-series,

- Clear goal of achieving a continuous and high resolution monitoring of our environment to better understand climate evolution, water resources, geomorphology, seismotectonics, etc.

- COSI-Corr technology is being transferred to **Imagin’Labs Corporation, a Caltech spin-off**, to propose routine processing of large data sets and expert processing services.