COSI-Corr 2011

On-going studies and future developments

Sébastien Leprince, François Ayoub, and Jean-Philippe Avouac

California Institute of Technology, Pasadena, CA 91125, USA

The Co-registration of Optically Sensed Images and Correlation (COSI-Corr) software, which was first released on January 2007, is continuously evolving. This poster shows our latest contributions and on-going studies to make COSI-Corr a fully automated, robust, fast, and extremely accurate tool, for the study of time series from a variety of optical sensors. Our latest developments concern not only new technical algorithms such as improved adaptive resampling, automatic and robust tie-points matching, compensation of aliasing effects in sub-pixel phase correlation, and sensor-agnostic topography extraction, they also concern new software development methods.

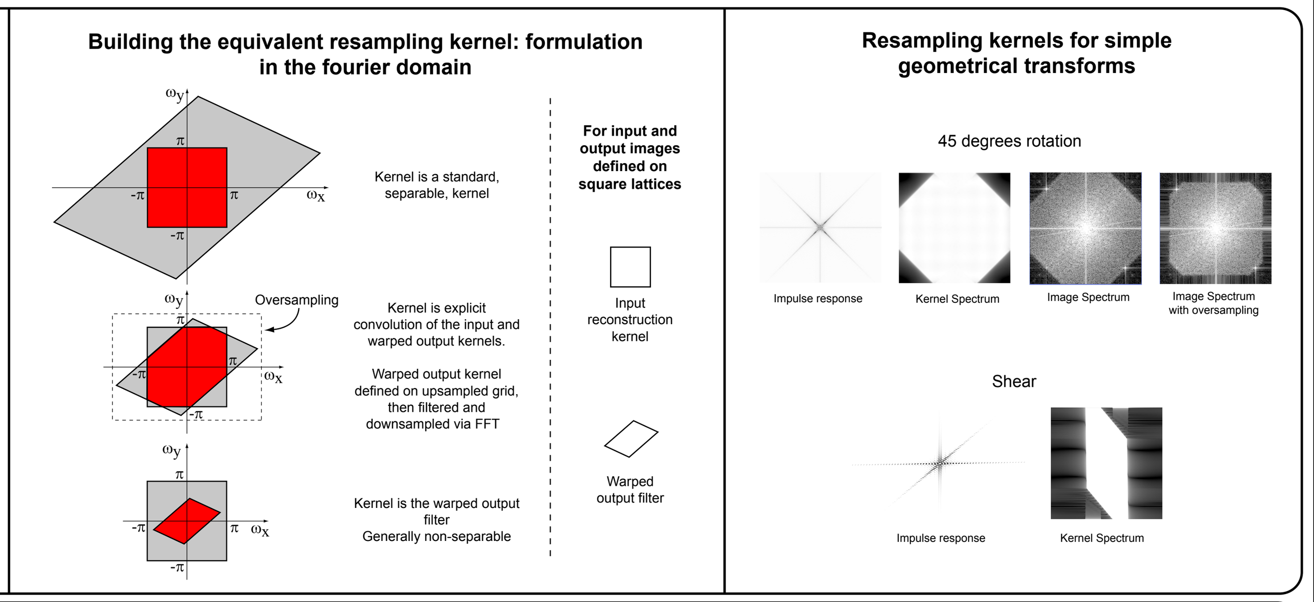
As COSI-Corr is increasing in complexity, we now must adopt the rigorous development procedures in effect in the software industry. Low level languages, multi-threaded processing and adequate source control and bug tracking are now integrated in our development cycle. In addition, our ambition is taking us toward large scale processing and analysis, and cluster and cloud computing solutions are being explored. As COSI-Corr is growing, the expertise of many more people is required. For several studies, you will notice the participation of additional collaborators. Orchestrating the many new projects is a challenging and exciting task.

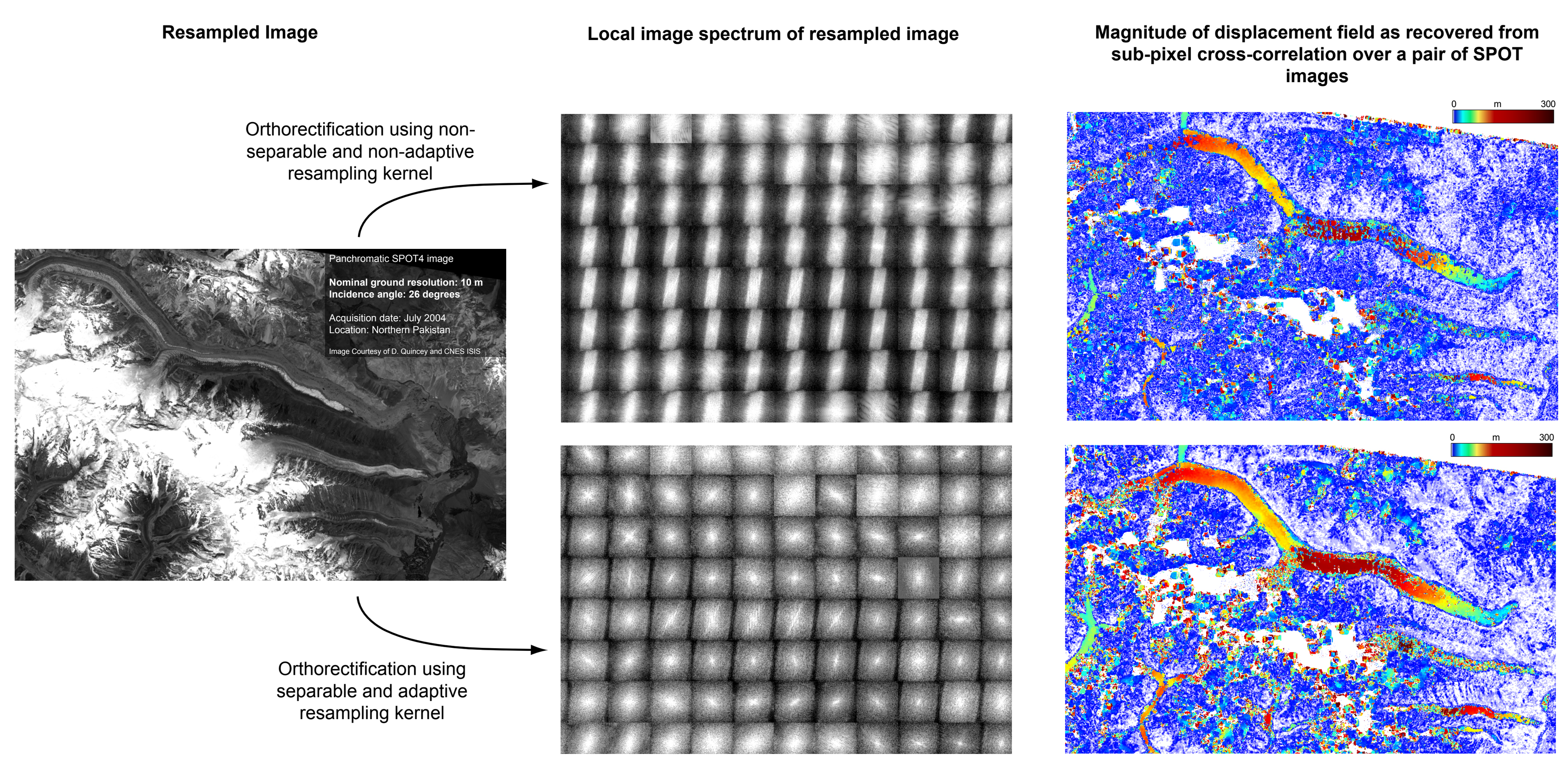
Rigorous Adaptive Resampling for High Resolution Image Warping

General resampling kernel in sensor geometry:

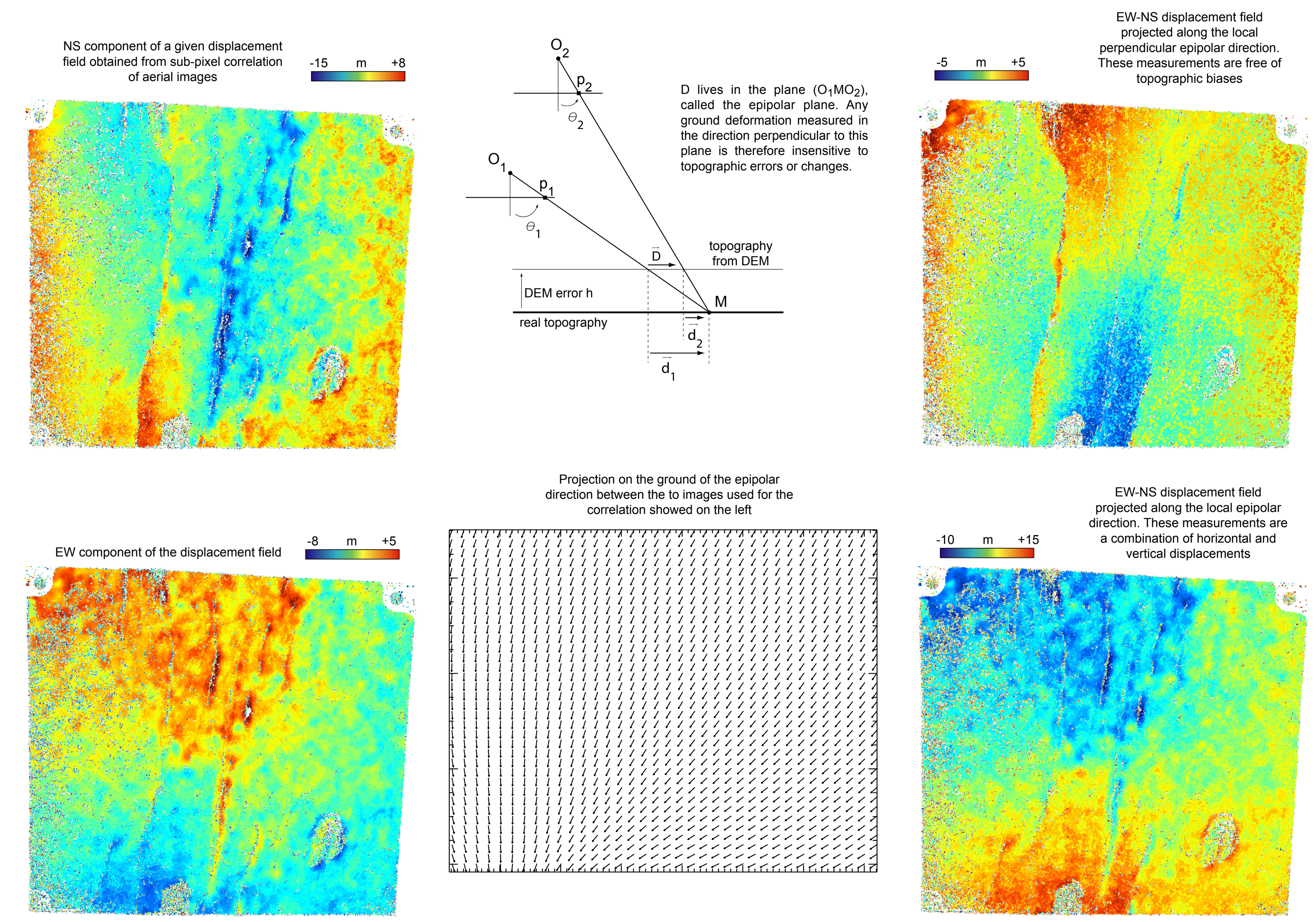
$$\rho_s(\mathbf{x}) = r_s(\mathbf{x}) \circledast h_g(\mathbf{J}\mathbf{x})|\mathbf{J}|,$$

- r_s reconstruction kernel in sensor geometry,
- h_g anti-aliasing filter in the mapped geometry (on the ground),
- $\mathbf{J}$ Jacobian of the direct warping function.





Epipolar Perpendicular Projection: Suppressing Topo Biases

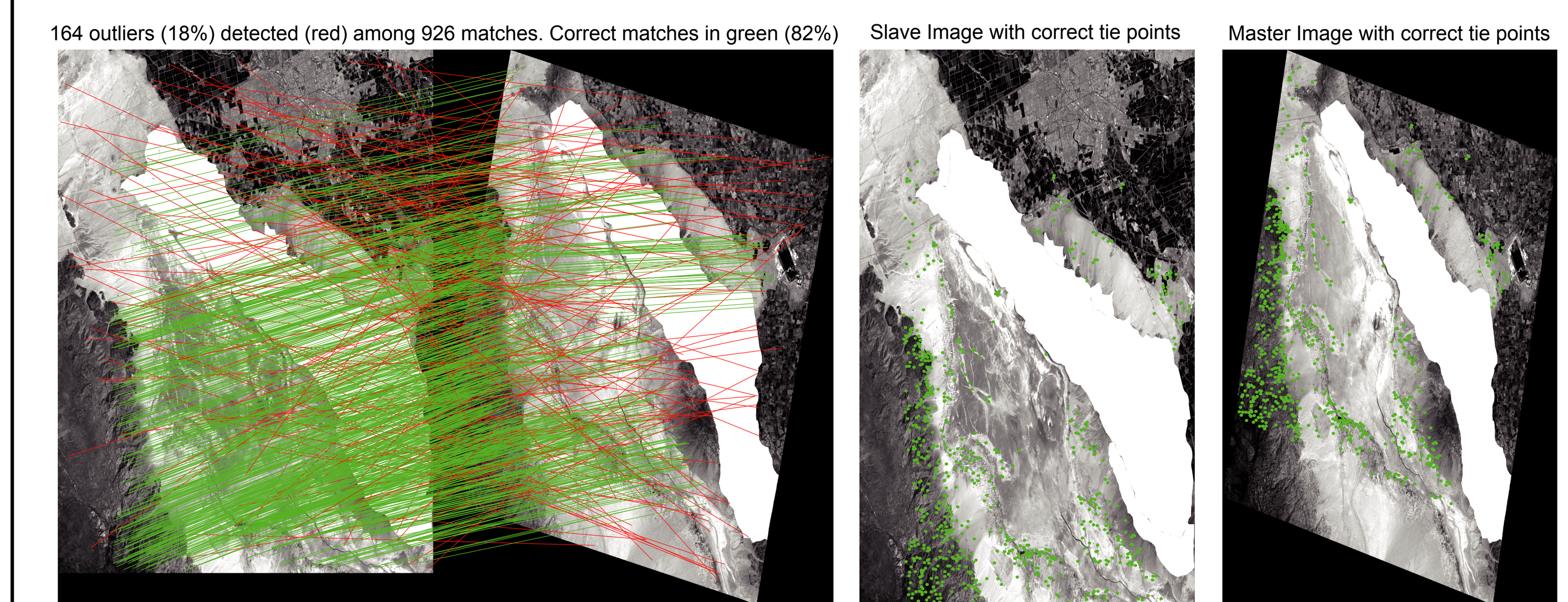


See James Hollingsworth poster for more details on this study

Robust Selection of tie-points between multi-temporal images

We developed a method, APERS (Affine Parameters Estimation by Random Sampling), to robustly identify correct and false matches from automatic feature matching algorithms such as SIFT (Scale Invariant Feature Transform). Correct matches are defined such that they follow a global affine transform. Outliers in the matching are always correctly identified up to a proportion of 90% of outliers.

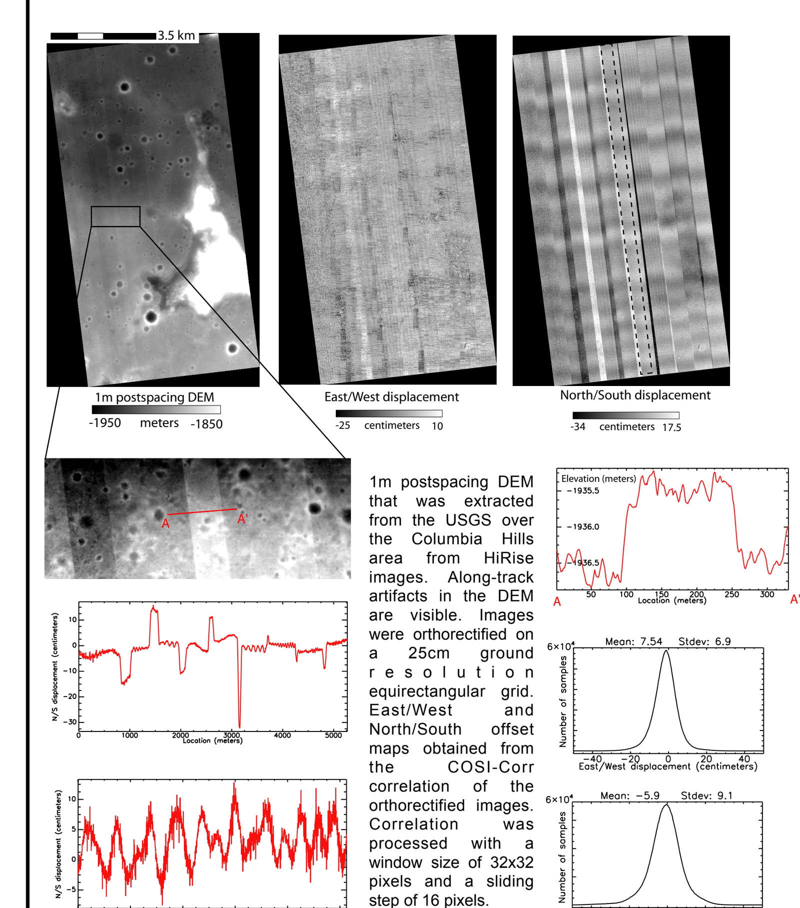
Below, an example of tie-points matching using SPOT 5 images before and after the El Mayor Cucapah earthquake, Mw 7.2, from April 4th, 2010. The fault area was masked to avoid biasing subsequent registration.



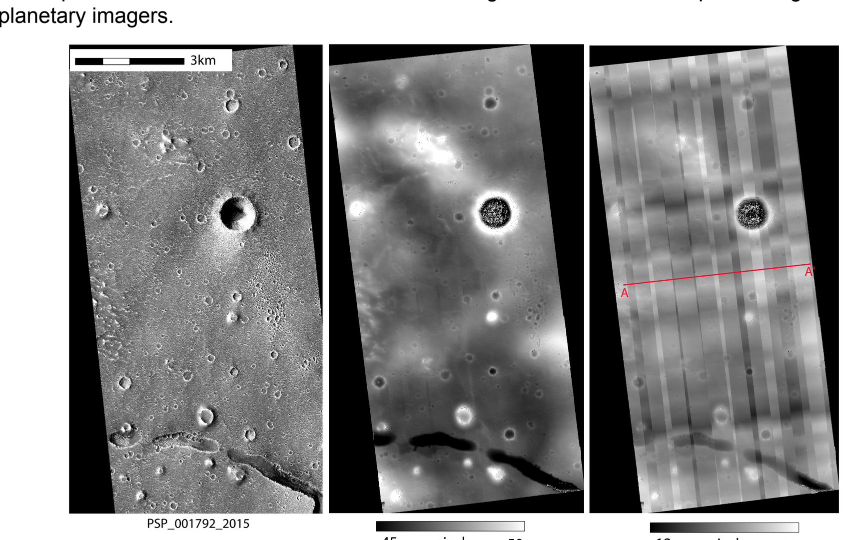
Collaboration with Simon Beckouche, ENS Cachan. See his poster for technical details.

Processing of images from planetary surfaces, in particular HiRISE images from Mars

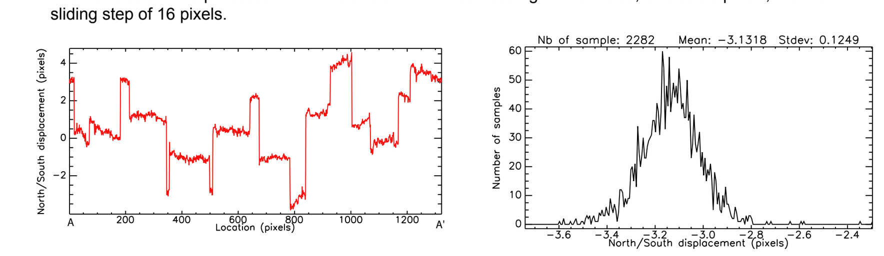
Characterization of geometrical artifacts in HiRISE images. We detect CCD and jitter artifacts and assess the accuracy of standard ISIS procedures as provided by the USGS. A newly developed sensor model will allow accurate co-registration of multi-temporal images from planetary images.



1m postspacing DEM that was extracted from the USGS over the Columbia Hills area from HiRISE images. Along-track artifacts in the DEM are visible. Images were orthorectified on a 25cm ground resolution equirectangular grid. East/West and North/South offset maps obtained from the COSI-Corr correlation of the orthorectified images. Correlation was processed with a window size of 32x32 pixels and a sliding step of 16 pixels.



Map of horizontal offsets measured between 2 HiRISE images acquired over the Hephaestus Fossae area. The correlation was processed with COSI-Corr with a decreasing window size, 512 to 32 pixels,and with a sliding step of 16 pixels.



Study in collaboration with Nathan Bridges, Applied Physics Laboratory, MD

Improved Development Process for Quality Software

Fast processing using C++ Intel compiler and Intel Math libraries

Multi-threaded code

Distributed source control

Automatic builds

Bug tracking system

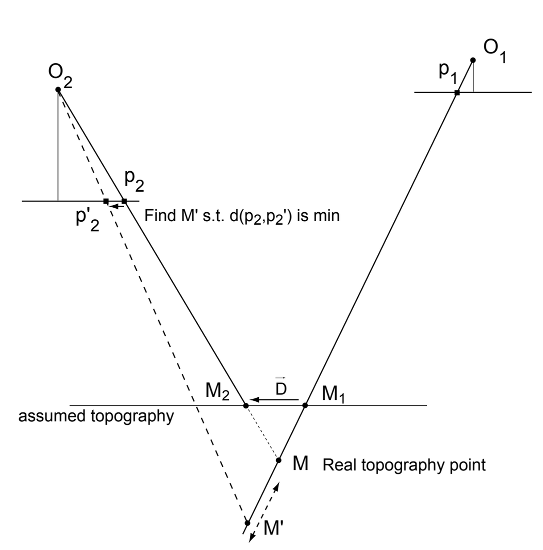
Automatic testing procedures

Portable code for Linux and Windows (Mac coming soon)

32 and 64 bits binaries

Work in collaboration with Jiao Lin and Michael Aivasiz, Caltech CACR

Topography Extraction from Stereo-pairs

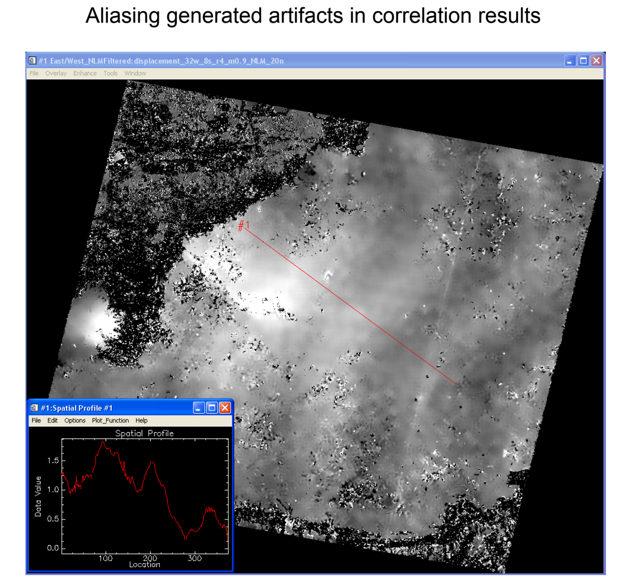


M_1 is the point on the ground seen by the pixel p_1, assuming some topography model. The disparity map computed between the two pseudo ortho-images gives a disparity D at M_1. Via inverse projection, the pixel p_1 in image 1 should then be mapped to the pixel p_2 in image 2. The real topography point M is found when the distance between p_2 and p_2' is minimum. The pixel p_2' is the projection in the focal plane of image 2 of the point M', which belongs to the ray O_1p_1. This formulation satisfies the fundamental epipolar constraint and can be used irrespective of the sensor geometry.

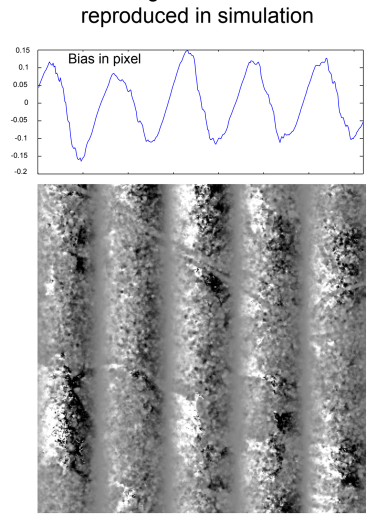
Aliasing Effects in Phase Correlation: First Steps Toward Unbiased Measurements

Observations and simulation

Aliasing generated artifacts in correlation results



Aliasing artifacts can be reproduced in simulation



Theoretical considerations and bias reduction

Let's consider a positive aliased frequency $\omega \in [0, \frac{\omega_s}{2}] = [0, \pi[$

$$\begin{cases} \widehat{f}_s(\omega) = \widehat{f}_c(\omega) + \widehat{f}_c(\omega - 2\pi) \\ \widehat{g}_s(\omega) = \widehat{f}_c(\omega)e^{-i\omega x_0} + \widehat{f}_c(\omega - 2\pi)e^{-i(\omega-2\pi)x_0} \end{cases}$$

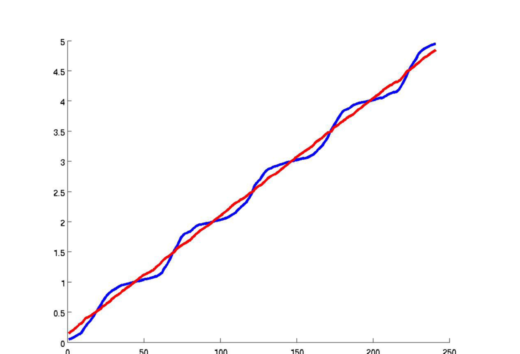
In the case of a negative aliased frequency $\omega \in]-\frac{\omega_s}{2}, 0] =]-\pi, 0]$

$$\begin{cases} \widehat{f}_s(\omega) = \widehat{f}_c(\omega) + \widehat{f}_c(\omega + 2\pi) \\ \widehat{g}_s(\omega) = \widehat{f}_c(\omega)e^{-i\omega x_0} + \widehat{f}_c(\omega + 2\pi)e^{-i(\omega+2\pi)x_0} \end{cases}$$

In this case the correlation is given by:

$$corr = e^{i\omega x_0}\frac{\varepsilon}{|\varepsilon|}$$

- for $\omega \in [0, \pi[$:
$$\varepsilon = |\widehat{f}_c(\omega)|^2 + |\widehat{f}_c(\omega - 2\pi)|^2 e^{-2i\pi x_0} + \overline{\widehat{f}_c(\omega)}\widehat{f}_c(\omega - 2\pi) + \widehat{f}_c(\omega)\overline{\widehat{f}_c(\omega - 2\pi)}e^{-2i\pi x_0}$$
- for $\omega \in]-\pi, 0]$:
$$\varepsilon = |\widehat{f}_c(\omega)|^2 + |\widehat{f}_c(\omega + 2\pi)|^2 e^{2i\pi x_0} + \overline{\widehat{f}_c(\omega)}\widehat{f}_c(\omega + 2\pi) + \widehat{f}_c(\omega)\overline{\widehat{f}_c(\omega + 2\pi)}e^{2i\pi x_0}$$



Blue: 1-D disparity, in pixels, recovered from a linearly streched image fully aliased.

Red: 1-D disparity recovered when the aliasing model is accounted for in the formulation

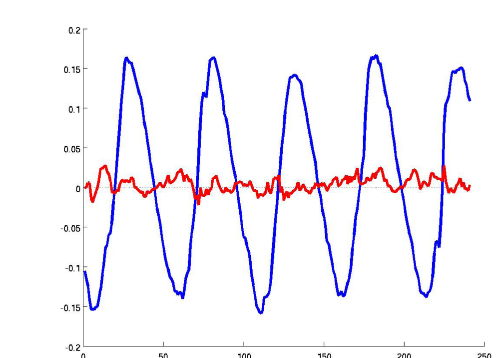
When we consider the expectation of ε we get the expectation of crossed terms is equal to 0

- for $\omega \in [0, \frac{\omega_s}{2}] = [0, \pi[$
$$\boxed{\mathbb{E}(\varepsilon) = |\widehat{f}_c(\omega)|^2 + |\widehat{f}_c(\omega - 2\pi)|^2 e^{-2i\pi x_0}}$$
- for $\omega \in]-\frac{\omega_s}{2}, 0] =]-\pi, 0]$
$$\boxed{\mathbb{E}(\varepsilon) = |\widehat{f}_c(\omega)|^2 + |\widehat{f}_c(\omega + 2\pi)|^2 e^{2i\pi x_0}}$$

Instead or minimizing $|corr - exp(i\omega x)|^2$ we minimize

- $|corr - exp(i\omega x + (\frac{\omega}{2\pi - \omega})^2)|^2$ for positive frequencies
- $|corr - exp(i\omega x + (\frac{\omega}{2\pi + \omega})^2)|^2$ for negative frequencies.

This equation is assuming a linearly decreasing MTF for simplicity



Blue: 1-D disparity residual, in pixels, between standard phase correlation on aliased images and expected disparity.

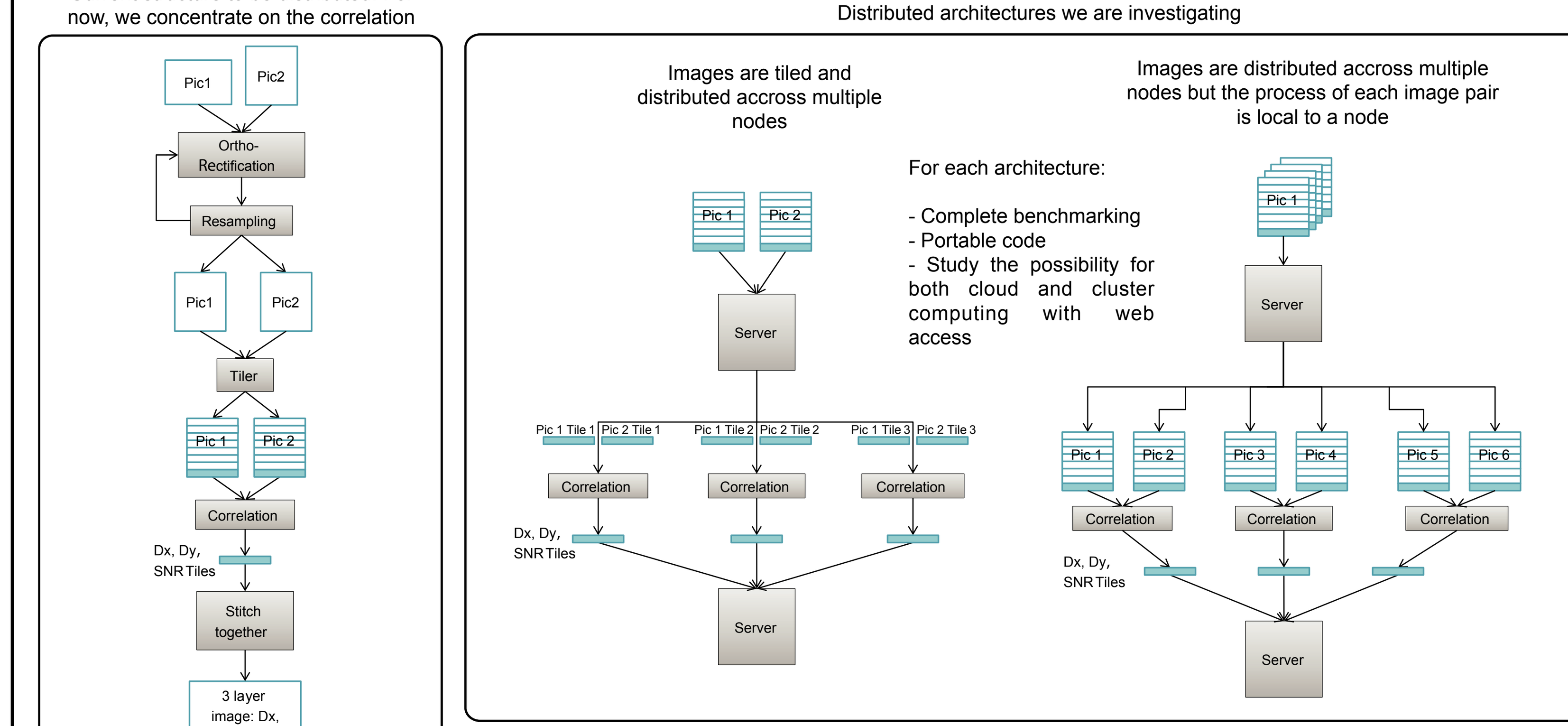
Red: 1-D disparity residual when the aliasing model is accounted for in the formulation

Study with Thomas Pumir, ENS Cachan, France

Distributed Cluster Computing for Fast and Large-Scale Analysis

Current structure to be distributed. For now, we concentrate on the correlation

Distributed architectures we are investigating



For each architecture:

- Complete benchmarking
- Portable code
- Study the possibility for both cloud and cluster computing with web access

Study part of a Harvey Mudd Computer Science Clinic project 2010-2011

References:

S. Leprince, S. Barbot, F. Ayoub and J. P. Avouac, "Automatic and Precise Ortho-rectification, Coregistration, and Subpixel Correlation of Satellite Images, Application to Ground Deformation Measurements", IEEE Transactions on Geoscience and Remote Sensing, Vol.45, No.6, June 2007.

F. Ayoub, S. Leprince and J.P. Avouac, "Co-registration and Correlation of Aerial Photographs for Ground Deformation Measurements," ISPRS Journal of Photogrammetry and Remote Sensing, Volume 64, Issue 6, Pages 551-560, November 2009

P. Heckbert, "Fundamentals of texture mapping and image warping," Master's thesis, Technical Report No. UCB/CSD-89-516, University of California, Berkeley, 1989.

David G. Lowe, "Distinctive image features from scale-invariant keypoints," International Journal of Computer Vision, 60, 2 (2004), pp. 91-110.

H. Stone, M. Orchard, E.C. Chang, "Subpixel Registration of Images," Proceedings of the 1999 Asilomar Conference on Signals, Systems, and Computers, 1999