Efficient Denoising of 2D Scientific Data via Non-Local Means

Application to ground deformation measurements

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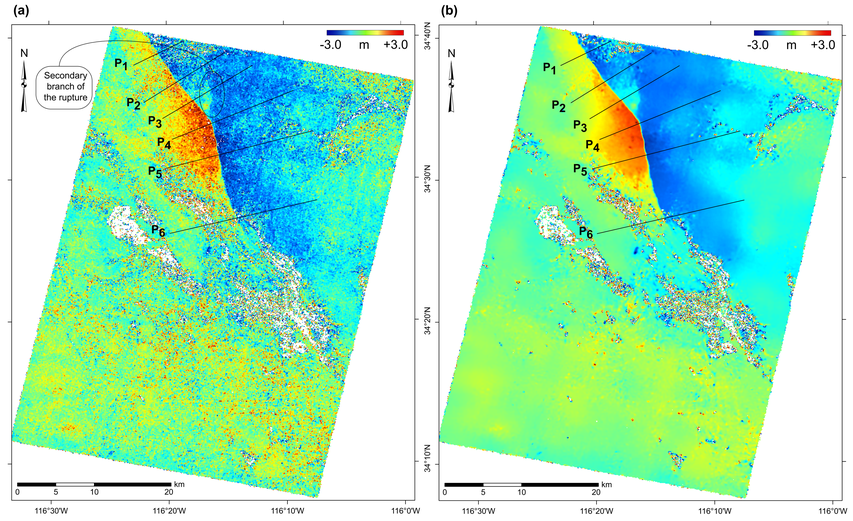
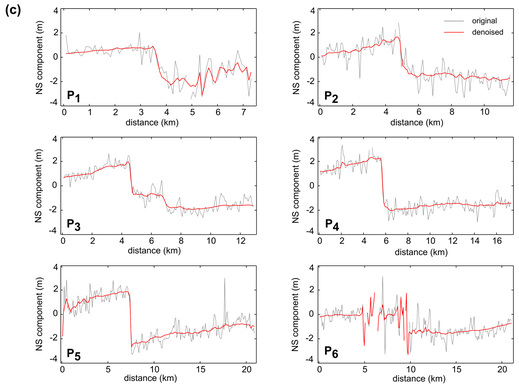
Denoising via Non-Local Means has proven to be one of the best techniques for digital image restoration. Here, we have implemented an extension for scientific data, accounting for missing values, and, if available, for the signal-to-noise ratio (SNR) of the values. Indeed, scientific data are often the result of some measurement, and they are commonly associated with some known uncertainty. NL-means filtering is traditionally not fully taken advantage of due to its prohibitive computational cost. Several approximate implementations, trading off denoising capabilities for execution time, have been proposed. Here, we propose a rigorous implementation, with no approximation, and instead achieve fast execution by taking advantage of the vectorized architecture of modern processors. The technique is applied to the correlation measurements of the displacement field induced by the 1999 Hector Mine, and by the 1992 Landers earthquakes. The displacement fields are denoised without introducing any visible artifact, and because fault discontinuities are well preserved, a clear strain map can be derived from the denoised data.

The 1999, Mw 7.1 Hector Mine Earthquake





(a) North-South component of the displacement field induced by the 1999 Hector Mine earthquake, CA. Measurements produced from the cross-correlation of a 1998, 10m resolution, SPOT4 image, and a 2000, 10m resolution, SPOT2 image. Displacement field sampled every 80m.

(b) Displacement field in **(a)** denoised via Non-Local Means. The structure of the data is well preserved and no artifacts are introduced, allowing precise measurement of the displacement field. For instance, the secondary branch of the rupture is well denoised, although its amplitude is on the order of the noise level. Low frequency undulations are detected in the denoised images, most likely betraying attitude artifacts from the satellite, undetected in the noisy measurements.

(c) Profiles taken from (a) and (b). The fidelity to the underlying data is evident.

References:

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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.

S. Leprince, F. Ayoub, Y. Klinger and J.P. Avouac, "Co-Registration of Optically Sensed Images and Correlation (COSI-Corr): an Operational Methodology for Ground Deformation Measurements," IEEE International Geoscience and Remote Sensing Symposium (IGARSS 2007), Barcelona July 2007.

F. Ayoub, S. Leprince and J.P. Avouac, "Co-registration and Correlation of Aerial Photographs for Ground Deformation Measurements," Submitted to ISPRS.

Denoising via Non-Local Means: General Principle

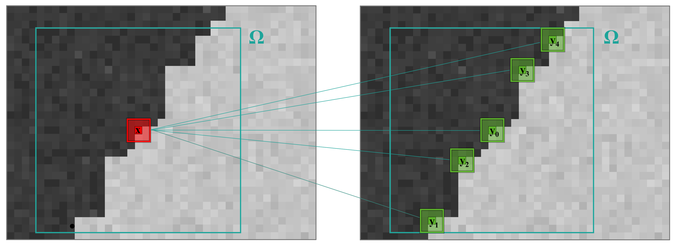


Illustration of the Non-Local means principle. The restored value of pixel ***x*** (in red) is the weighted average of all intensities of pixels ***y*** (in green) in the search area Ω, based on the similarity of their intensity neighborhoods ***u(x+t)*** and ***u(y+t)***

* Average of pixels with similar configuration in a whole Gaussian neighborhood

$$NL_h[u](\mathbf{x}) = \frac{1}{C(\mathbf{x})} \int_{\Omega} e^{-\frac{1}{h^2} \int_{\mathbb{R}^2} G_a(t) |u(\mathbf{x}+t) - u(\mathbf{y}+t)|^2 dt} \; u(\mathbf{y}) \; d\mathbf{y}$$

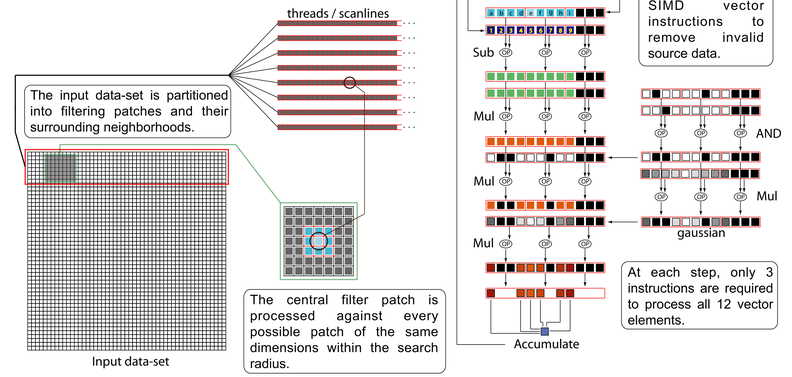
where G_a is a Gaussian kernel of standard deviation a, and h acts as a filtering parameter.

* Pixels of the whole search area take part of the average (non-local).

Fast Vector-Parallel Implementation in COSI-Corr

The Non-Local means algorithm exhibits both task parallelism (below) and data parallelism (right). The task parallelism is exploited via implementation of the classic "fork-join" model of parallel processing. A given scanline to be processed is assigned a seperate thread of execution which filters the data points independantly of the other scanlines in the data set. A synchronization mechanism guarantees no scanline is processed twice by accident.

The SIMD (Single Instruction Multiple Data) vector-processing instructions of the Intel processor family are used to exploit the data parallelism of the non-local means algorithm by simultaneously processing 4 32-bit floats per instruction within each worker thread.



The 1992, Mw 7.3 Landers Earthquake from Aerial Images Strain Map Computation