Variational Stationary Noise Remover

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Third light sheet microscopy workshop
Starting observation

In many applications, **structured noise** degrades the images.

**SPIM** - Stripes due to light absorption and scattering.
Left: Xenopus leavis’s late taibud (40X NA 0.8).
Right: Multicellular Tumor Spheroid (20X NA 0.5).
Examples of images with stripes

Scanning electron microscope: Stripes in a sintered specimen of Cerium Oxyde.

Examples of images with stripes

Ion beam nanotomography: Stripes in particles of cement paste.

Other applications where correlated noise occurs.

- SPIM.
- Atomic force microscopy.
- Electron tomography.
- Synchrotron X-ray microscope.
- Ion beam nanotomography (waterfall effect).
- MODIS images (atmosphere imaging).
- Digital elevation models (satellite imaging).
- Imaging under turbulence.
- ...
Motivation - Standard denoising methods fail

Left: original image. Right: denoised image using Gaussian smoothing.
Motivation - Standard denoising methods fail

Left: original image. Right: denoised image using anisotropic diffusion.
Motivation - Standard denoising methods fail

Left: original image. Right: denoised image using bilateral filtering.
Why do standard methods fail?

- **Main reason:** standard methods rely on a white noise assumption. White means uncorrelated pixelwise.
- **Our objective:** design methods for correlated/stationary noise.

White noise (left) VS stationary noise (right).
What is a stationary noise?

Translating the sample in space does not change its probability.

Left: A sample of stationary noise.
Right: the same sample translated.

A natural assumption: we have no a priori knowledge on the location of features. They appear randomly.
How can we generate stationary noises?

- The class of stationary noises is too wide for numerical processing.
- We restrict to the class of noises obtained by replicating and translating an elementary pattern $\psi$.

This can be achieved by convolving white noise with a pattern:

$$\lambda \ast \psi(x) = \sum_{y} \lambda(y) \psi(x - y).$$
Examples of stationary noises
Model of image formation

A noisy image $u_0$ is the sum of:

- the original image $u$.
- a stationary noise $b$.

$$u_0 = u + b$$

where

$$b = \sum_{i=1}^{m} \lambda_i \ast \psi_i$$

$b$ is a sum of stationary processes.
The VSNR algorithm

**INPUT:**

- A pattern:

  ![Pattern Image]

- A white noise statistics:

  ![White Noise Images]

- A regularization parameter: tunes the algorithm.

**OUTPUT:**

- A “nice” image.
The VSNR algorithm

The algorithm finds the most likely image.

Turns out to be a convex optimization problem.

\[
\argmin_{\lambda \in \mathcal{R}^{m \times n}} \left( \left\| \nabla \left( u_0 - \sum_{i=1}^{m} \lambda_i \ast \psi_i \right) \right\|_1 + \sum_{i=1}^{m} \phi_i(\lambda_i) \right)
\]

More details in:


Examples of application - simulated data (1)

Left: noisy image. Right: detail.

Denoised images.
Examples of application - simulated data (2)

Left: noisy image. Mid: 1st component. Right: 2nd component.

Recovered components.
Examples of application - SPIM image of a zebrafish

Original - TV-L2 (standard) - $H^1$-norm (fast) - VSNR
Examples of application - SPIM image of a zebrasfish

Original
Examples of application - SPIM image of a zebrasfish

Denoised
Examples of application - Ion bean nanotomography

Original
Examples of application - Ion bean nanotomography

Denoised
Examples of application - SEM
Examples of application - SEM

Denoised
Examples of application - SPIM image of a spheroid
Examples of application - SPIM image

3D rendering using Imaris.
Left: original. Right: denoised.
Conclusion

Main messages:

➢ Standard methods unadapted to the removal of correlated noise.
➢ Development of a versatile method for stationary noise.
➢ New theoretical bases (see preprints).
➢ Matlab implementation available on:

www.math.univ-toulouse.fr/~weiss/index.html

Perspectives:

➢ Real 3D implementation.
➢ Acceleration using GPU programming.
➢ FIJI implementation.


Ending words

- ♣ Thanks you for your attention ♣ -

– ♥ Thanks again to the organizers ♥ –

— ♠ Please welcome warmly the next magical speaker! ♠ —