A feature-preserving denoising algorithm to improve the quality of geomorphic analysis

John Stevenson[1], Xianfang Sun[2], Neil Mitchell[3]

1. Edinburgh University, School of Geosciences, Edinburgh, UK (john.stevenson@ed.ac.uk). 2. Cardiff School of Computer Science, Cardiff University, Queen's Buildings, 5 The Parade, Cardiff, CF24 3AA, UK. 3. School of Earth Atmospheric and Environmental Sciences, University of Manchester, Williamson Building, Oxford Road, Manchester, M13 9PL, UK

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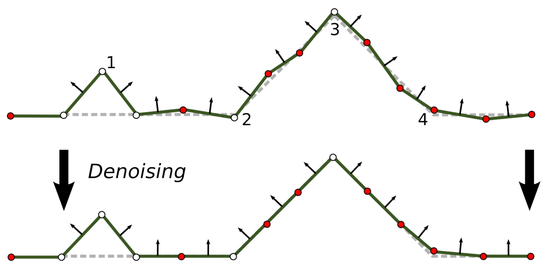
Summary

- We introduce an algorithm that denoises three-dimensional objects while preserving sharp features. It is free to download and simple to use on both raster and vector data.
- Compared to those filtered to an equivalent level with a mean filter, data smoothed by the denoising algorithm are closer to the original data and to the ground truth.
- The feature-preserving nature of the algorithm allows significant smoothing to be applied to flat areas of topography, while limiting the alterations made in mountainous regions.
- The algorithm has applications in fields such as hydrological modelling and landslide prediction.

1. How the algorithm works



Schematic, two-dimensional representation of how the algorithm handles nodes and the normals of the faces between them.

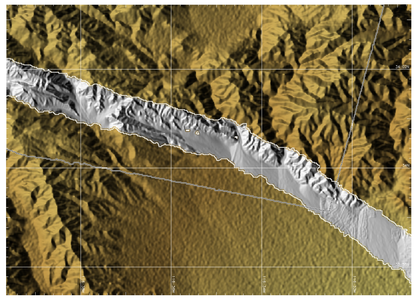
The algorithm uses the **normals** to faces between datapoints. The best orientation for the normal to each face is calculated from a **weighted mean** of the normals of the surrounding faces.

If the orientation of the normal of a face is **too different** from its neighbours (white nodes), it is excluded from the calculation (**weight=0**). This way, sharp edges are preserved.

The **threshold setting (T)** controls which normals are included in the calculations. High threshold settings preserve finer detail by may also preserve noise.

The nodes are moved in a **number of iterations (n)** to bring the normal orientations towards the calculated value. Increasing the number of iterations leads to increased smoothing.

2. Denoising SRTM data



Shaded relief map of the SRTM dataset covering the Desert Hot Springs area of SE California. The grey band running through the map is the region for which there is also LiDAR data, collect by the United States Geological Survey.

SRTM, LiDAR and the desert

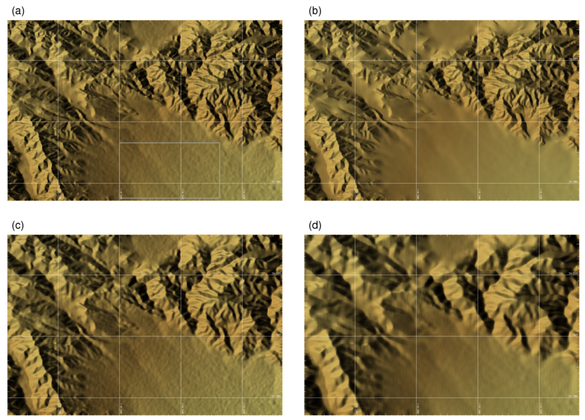
A region in the Californian desert was chosen for its range of relief, thin vegetation and availability of topographic data from a variety of sources.

Shuttle Radar Topography Mission (SRTM) data has a pixel size of ~30 m and a mean vertical accuracy of +/- 16 m. It suffers from random 'speckle noise', which causes non-existent 'dunes' to appear in areas that are actually flat.

LiDAR data have a pixel size of ~1 m and a mean vertical accuracy of +/-0.15 m. They were used to ground-truth the denoised data.

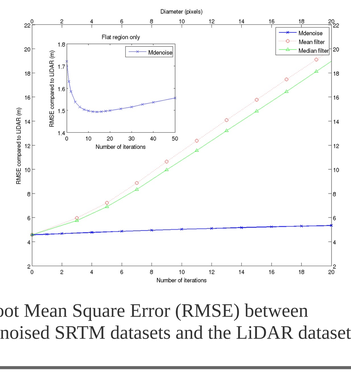
Smoothing lowlands while preserving mountain peaks

- The SRTM data were denoised to remove speckle noise, and the results were compared with data smoothed by mean filtering.
- Examples (a) + (c), and (b) + (d), have been been processed so that they are geostatistically equivalent in the flat area in the white rectangle shown in (a).
- The extra detail that is preserved in mountain regions in the datasets denoised by Sun's algorithm can be clearly seen.



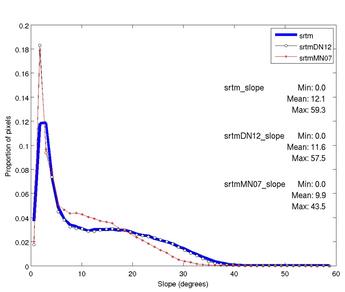
Denoised/smoothed SRTM datasets. (a) Sun's algorithm - 5 iterations. (b) Sun's algorithm - 20 iterations. (c) Mean filter - diameter 5 pixels. (d) Mean filter - diameter (9 pixels).

3. Comparison with mean or median filtering



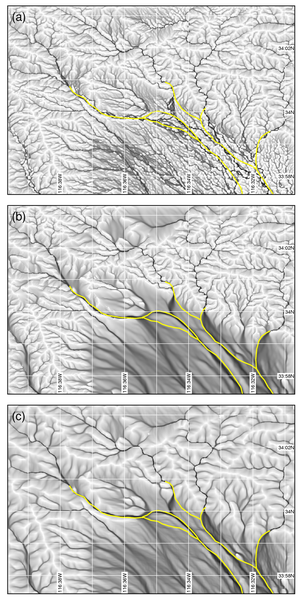
Root Mean Square Error (RMSE) between denoised SRTM datasets and the LiDAR dataset.

- The denoised SRTM dataset is closer to the original data (lower RMSE) than those smoothed with mean or median filters.
- The slope distribution of the denoised SRTM dataset is closer to the original data than those smoothed with mean or median filters.



Distribution of slopes in the original and denoised SRTM dataset.

4. Hydrological modelling



Flow accumulation maps calculated from SRTM data, representing the upstream contributing area for each cell. Dark colours indicate the predicted locations of streams and rivers. The solid yellow lines are actual river channels, as digitised from a Landsat image of the area.

(a) Original SRTM. Note how noise disrupts channels in the flat part of the region.
(b) Denoised with Sun's algorithm (12 iterations). The channels are recovered.
(c) Smoothed with a median filter (7 pixel diameter). The channels are recovered but details such as small channels are lost in the mountains.

Noise in SRTM data disrupts hydrological models, for example by making channels appear in the wrong locations. Both Sun's algorithm and median filtering improve this, but Sun's algorithm also preserves sharp features in mountain regions.

Further Reading

Try it yourself:

Sun's Denoising Algorithm is free to install, distribute and modify (GPL2). It runs on Windows, Linux and Mac systems. Find examples, instructions and installation files at:

http://personalpages.manchester.ac.uk/staff/neil.mitchell/mdenoise/

Published papers:

- Sun, X., P. L. Rosin, R. R. Martin, and F. C. Langbein (2007), *Fast and Effective Feature-Preserving Mesh Denoising*, Visualization and Computer Graphics, IEEE Transactions on, 13(5), 925–938.
- Stevenson, J. A., X. Sun, and N. C. Mitchell (2010), *Despeckling SRTM and other topographic data with a denoising algorithm*, Geomorphology, 114(3), 238–252, doi:10.1016/j.geomorph.2009.07.006.

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