Wavelet de-noising of terrestrial laser scanner data for the characterization of rock surface roughness

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Measurement of rock surface roughness

- Roughness: short-wavelength irregularities of the rock surface;

- Roughness is an important property in the study of slope stability, strength, deformability and permeability of the rock;

- Often measured by using manual tools;

- **Can roughness be measured in laser range data?**
Manual measurement vs. laser scanning

_manual method:
- Labour-intensive;
- Time-consuming;
- Limited to accessible areas.

_laser scanner:
- Fast;
- Accurate;
- Large coverage;
- High spatial resolution;
- Can reach non-accessible areas;
- Data contain Noise!
Manual measurement vs. laser scanning
Wavelet de-noising of laser range data

Noisy profile

Wavelet decomposition

Estimation of noise level

Threshold selection

Application of threshold

Wavelet reconstruction

De-noised profile

Penalized

Soft thresholding

Median Absolute Deviation

Fixed-form

Hard thresholding

DWT

WP

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Calculating the threshold

Standard deviation of the noise:
\[ \sigma_n = \frac{\text{Median}(|w_{l,k}|)}{0.6745} \]

Fixed-form threshold for DWT:
\[ t^f = \sigma_n \sqrt{2 \log(d)} \]

Fixed-form threshold for WP:
\[ t^f = \sigma_n \sqrt{2 \log \left( d \log(d) / \log(2) \right)} \]

Penalty function:
\[ t^* = \arg \min_{t=1,\ldots,n} \left[ -\sum_{k=1, k < t} w_k^2 + 2t\sigma_n^2(\alpha + \log(\frac{n}{t})) \right] \]

Penalized threshold:
\[ t^p = |w_{t^*}| \]

Penalized low: \( \alpha = 1.5 \), medium \( \alpha = 2.0 \), high: \( \alpha = 5.0 \)
Thresholding modes

Hard thresholding

Soft thresholding
Quantification of roughness

Roughness length method

\[ \log_e (s(w)) = \log_e A + H \log_e w \]

\[ D = 2 - H \]
Experiments

Study area
Tailfer, Belgium

Laser reflectance image
Extracting roughness profiles from laser data

Profiles are marked by white chalk. Chalk traces are visible in laser range data.
Surface fitting

<table>
<thead>
<tr>
<th></th>
<th>Plane fitting using PCA</th>
<th>Bilinear surface fitting</th>
<th>2\textsuperscript{nd} order polynomial (curved surface)</th>
</tr>
</thead>
<tbody>
<tr>
<td>RMS Residuals (mm)</td>
<td>15.1</td>
<td>15.1</td>
<td>14.1</td>
</tr>
</tbody>
</table>

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Results: raw laser data

Manually measured profile:
\[ D = 1.17 \]
\[ A = 0.02 \]

Laser profile:
\[ D = 1.96 \]
\[ A = 0.21 \]

Expected range of \( D \): \( 1.1 < D < 1.8 \)
De-noising results: effect of decomposition method

The two decomposition methods lead to similar fractal dimension values.
De-noising results: effect of decomposition method

Amplitude values are also similar for both decomposition methods.
De-noising results: effect of thresholding mode

- Fractal dimension values resulting from soft thresholding are below the expected range;
- Hard thresholding results in fractal dimension values within the expected range (with one exception).
De-noising results: effect of thresholding mode

- Amplitude values resulting from soft thresholding are closer to reference values;
- Amplitude values resulting from hard thresholding are about 4 times smaller than that of the raw laser data;
De-noised roughness profiles

Discrete Wavelet Transform, Penalized Low, Soft Thresholding:

Wavelet Packet, Fixed Form, Hard Thresholding:
Summary and concluding remarks

• Roughness (millimeter-scale) can be measured in laser range data provided that data are de-noised;

• Wavelet de-noising leads to significant improvement of roughness parameters derived from laser profiles;

• DWT vs. WP decomposition → no significant impact;

• Hard vs. soft thresholding → hard thresholding yields more reliable estimates of roughness parameters;

• Future research: extension from 1-D profiles to 2-D patches.
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Thank-you for your attention!