Comparative analysis of roughness algorithms for the identification of active landslides

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1. Introduction

Surface roughness is one of the most common parameter used to describe landslide activity in quantitative geomorphology. Previous studies proved that topographic roughness is closely related to both landslide mechanics and features, and a number of different techniques have emerged over the year for this task reflecting the great variety of landforms and processes that affect unstable slopes.

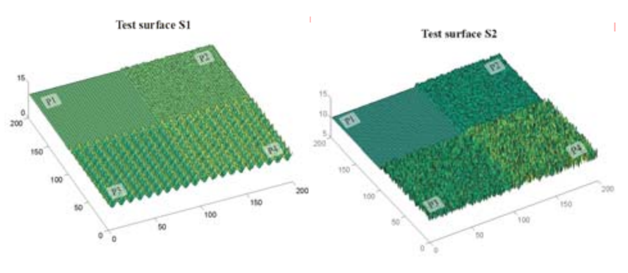
We perform a comparative analysis of several methods used in literature in order to evaluate quantitatively which algorithms are best suited to discriminate active landslides and to predict them for automated mapping purposes.

The algorithms are tested on artificial test surfaces as well as on real-world topography (LiDAR datasets of two case studies in the Northern Apennines, Italy).

2. Roughness algorithms

Parameter	Algorithm	Detrending	Reference
RMS Height	$RMSH=\left[\frac{1}{N^2-1}\sum_{i=1}^{N^2}(z_i-\bar{z})^2\right]^{1/2}$	Yes	Shepard et al. (2001)
RMS Deviation	$RMSD=\left[\frac{1}{4(N-1)}\sum_{i=1}^{4(N-1)}(z_c-z_b)^2\right]^{1/2}$	Yes	Shepard et al. (2001)
RMS Slope	$RMSS=\left[\frac{1}{4(N-1)}\sum_{b=1}^{4(N-1)}\left(\frac{z_c-z_b}{\Delta x_b}\right)^2\right]^{1/2}$	Yes	Shepard et al. (2001)
Absolute Slope	$AS=\left[\frac{1}{4(N-1)}\sum_{b=1}^{4(N-1)}\frac{\lvert z_c-z_b\rvert}{\Delta X}\right]$	Yes	Kreslavsky and Head (1999)
Standard Deviation of Slope	$SDS=\left[\frac{1}{N^2}\sum_{i=1}^{N^2}(m_i-\bar{m})^2\right]^{0.5}$	No	Frankel and Dolan (2007)
Direction Cosine Eigenvalue	$DCE=[\ln(S1/S2)]^{-1}$	No	McKean and Roering (2004)
2D Semivariance	$\gamma=\frac{1}{2n}\sum_{i=1}^{n}[z(x_i,y_i)-z(x_{i+h},y_{i+h})]^2$	Yes	Glenn et al. (2006)
Wavelet Lifting Scheme	$WLS=\sum_{k=1}^{K}\frac{A(k)}{N^2}$	Yes	Hani et al. (2011)
Discrete Fourier Transform	$DFT=\sum_{f=f1}^{f2}V_{DFT}(f)$	Yes	Booth et al. (2009)
Continuous Wavelet Transform	$CWT=\sum_{f=f1}^{f2}V_{CWT}(f)$	No	Booth et al. (2009)

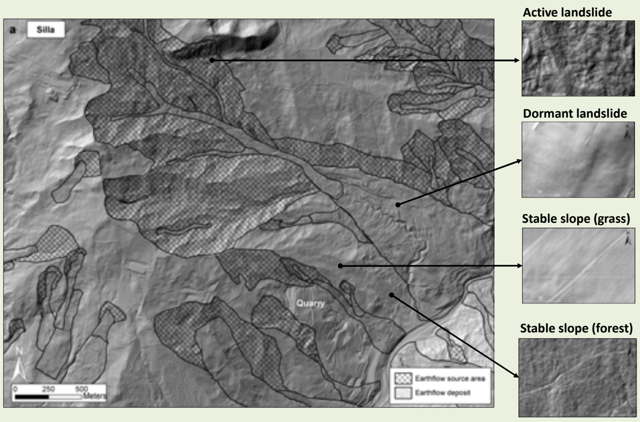
3. Tests on synthetic surfaces



All the methods perform reasonbly well on synthetic surfaces. Planar detrending is always reccomended to remove the general sloping trend from local topographic roughness.

Scale effects must be carefully considered. The algorithms based on the analysis of height variability (*RMSH, RMSD, WLS*) are more dependent on the size of the moving window than those based on the first derivatives of the DEM such as aspect or slope (*RMSS, AS, SDS, DCE*). Power-spectral-based methods (*DFT and CWT*) show low sensitivity to the size of the moving window, because the power spectrum is a measure of the spatial frequencies at all scales.

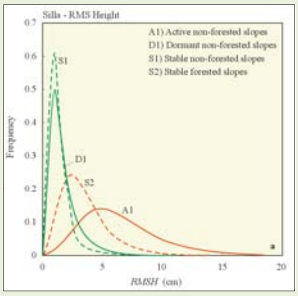
4. Comparative analysis on natural slopes



The capability of the different methods to discriminate between the morphological units recognized in the field was evaluated using the *effect-size* statistics.

Although the algorithms differ substantially in structure and complexity, they all show similar detection capability.

More complex algorithms, i.e. those based on a two-dimensional variogram (γ), discrete Fourier transform (*DFT*) and continuous wavelet transform (*CWT*) cannot outperform more simple methods like the wavelet lifting scheme (*WLS*), the direction cosine eigenvalues (*DCE*), and the *RMS*-based algorithms. Rather, in some cases simple methods show better results and provide higher values of the effect-size.

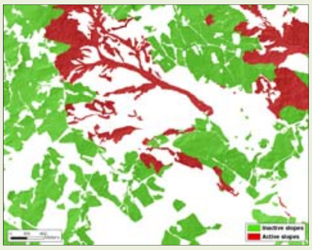


Sample results. Frequency histograms of the roughness values computed for several representative subsets using the RMS Height method (3x3 m moving window).

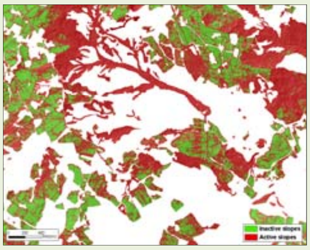
5. Capability to detect active landslides

Non-forested slopes

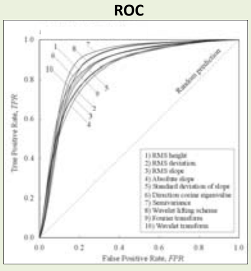
OBSERVED



PREDICTED



ROC

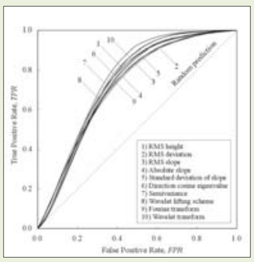


All the slopes

OBSERVED

PREDICTED *False alarms!*

ROC



In the case of non-forested slopes all the methods perform reasonably well. The area under the ROC ranges from 0.84 to 0.90 at Silla and from 0.73 to 0.81 at Valoria indicating high accuracy of the prediction.

The algorithms that performed relatively worse in terms of discrimination capacity of the representative patches (DFT and γ), perform relatively better when applied to a large area.

The accuracy of predictive maps decreases when forested slopes are included in the analysis, as forested areas are inherently rough, regardless of their morphological activity and all algorithms loose in discriminatory capability.

Despite the uncertainties in densely vegetated areas, there is adequate evidence from the results obtained that surface roughness can actually be used to automatically create accurate maps of active slopes over sparsely vegetated terrain.

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