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Influence of laser scanner range measurement noise on the quantification of rock surface roughness

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The roughness of rock surfaces is traditionally measured by using manual tools such as carpenter's comp and compass and disc clinometers. The manual measurements are limited to small samples at accessible parts of the rock. Terrestrial laser scanning is an attractive alternative measurement technique, which offers large coverage, high resolution, and the ability to reach inaccessible high rock faces. The application of laser scanning to the study of rock surface roughness faces a major challenge: the inherent range imprecision hinders the quantification of roughness parameters. In practice, when roughness is in millimeter scale it is often lost in the range measurement noise. The parameters derived from the data, therefore, reflect noise rather than the actual roughness of the surface. In this paper, we investigate the influence of laser scanner range measurement noise on the quantification of rock surfaces roughness. We show that measurement noise leads to the overestimation of roughness parameters. We also demonstrate the application of wavelet de-noising method to eliminating noise from laser scanner data and deriving realistic roughness parameters.

A slightly metamorphosed limestone rock in the east bank of the Meuse River in southern Belgium was scanned with a Faro LS880 terrestrial laser scanner. The scanner was positioned at approximately 5 meters distance to the rock surface, and operated at the highest possible angular resolution, i.e. 0.009 degrees. The resulting point cloud contained about 1.2 million points on the rock surface with a point-spacing of 1 mm on average. According to the technical specifications of the laser scanner, the nominal range precision at a perpendicular incidence angle, which was roughly the case in our scan, is between 0.7 mm and 5.2 mm respectively for objects of 90% and 10% reflectivity at a distance of 10 m. To serve as reference roughness data were also collected manually along three profiles on the rock surface by using a carpenter's profile gauge with metallic rods at 1 mm intervals. These profiles were marked with white chalk and were visible in the reflectance image of the laser scanner data. The point cloud was rotated into a horizontal surface by applying the principal component analysis. Then, guided by the chalk traces in the reflectance image, three corresponding roughness profiles were extracted from the point cloud with samples interpolated at regular 1 mm intervals. The results of this procedure were three pairs of roughness profiles derived correspondingly from the manual and laser measurements with the same length and spatial resolution. We refer to these as the horizontal, diagonal and vertical profiles.

Roughness parameters were derived from the corresponding profiles using the roughness length method (Malinverno, 1990). The method provides two parameters (Kulatilake and Um, 1999): i) fractal dimension (D) is an indication of the degree of auto-correlation or self-affinity of the surface topography, and is expected to be within the range of 1.2-1.7 for a 1D profile; ii) amplitude (A) is a measure of the amplitude of the roughness. Both parameters were estimated for roughness profiles from both the laser scanner data and the manual measurements.

The results showed a noticeable difference between the parameters obtained for the manual profiles and those for the laser profiles. The fractal dimension was estimated for the manually measured profiles at 1.17, 1.32 and 1.20 respectively for the horizontal, diagonal and vertical profile. For the corresponding laser profiles the estimated fractal dimensions were 1.96, 1.89 and 1.90 respectively. The amplitude of the manually measured profiles was estimated at a constant 0.2 for all three profiles, whereas the amplitude of the laser profiles varied from 1.9 to 2.1 across different directions. These results clearly show that roughness parameters derived from noisy laser range data are overestimated and are much larger than those estimated for reference manual profiles.

To demonstrate the role of wavelet de-noising method, different wavelet decomposition and thresholding methods were applied to the laser profiles and the resulting fractal dimension and amplitude values were compared to those of the reference profiles. The results showed that the fixed-form threshold applied in hard mode to the coefficients

obtained by the wavelet packet decomposition yields roughness parameters that are closer to those of the manually measured profiles and are also within the expected range. The fractal dimensions were found for the de-noised profiles to be 1.42, 1.38 and 1.30 respectively for the horizontal, diagonal and vertical profiles. The amplitudes of the de-noised profiles ranged from 0.5 for the horizontal and vertical profile to 0.6 for the diagonal profile.
In conclusion, the obtained results clearly show the influence of laser scanner range measurement noise on the derived roughness parameters. The application of the de-noising method leads to an improvement of the estimated roughens parameters; thus, wavelet de-noising should be seen as an important preprocessing step in roughness quantification using terrestrial laser scanner data.

References:
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