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Mapping rock surface roughness with photogrammetry

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ABSTRACT: In this study, the possibility of measuring rock surface roughness by means of open-source photogrammetric methods was investigated. With simple commercially available digital cameras, samples of varying roughness were measured. As a reference, the samples were also measured with a high-resolution white light strip scanner and additionally manually with a contour gauge. By comparing the digital datasets it became clear that the open-source structure-from-motion (SFM) algorithms were able to capture the overall topography but with clearly less accuracy than the white light scanner. This had a marked influence on the determined roughness parameter JRC (joint roughness coefficient). For smooth surfaces the JRC was higher than the reference value, for rough surfaces it was lower. In general, with the introduced method it was possible to reproduce the surface of the rocks but care has to be exercised when roughness parameters are to be deduced from the datasets.

1 INTRODUCTION

The shear strength of rock joints is primarily dependent on their surface roughness. In order to achieve a save and cost-efficient design in rock engineering it is desirable to measure joint roughness as accurate as possible. In the past, tools like contour gauges (Barton & Choubey 1977) and mechanical profilometers (e.g. Weissbach 1978) were used to measure unevenness of rock surfaces. Nowadays, high-resolution laser scanners (e.g. Fardin et al. 2001, Milne et al. 2009) or white light strip scanners (Tatone & Grasselli 2013) are applied to investigate rock surfaces. But, as these methods being cost-intensive, alternatives are needed. Therefore, in this study, open-source photogrammetric software was utilized to measure surface roughness. With a simple off-the-shelf digital camera in connection with well-established structure from motion algorithms five surfaces varying in roughness were investigated.

2 METHODS

Photogrammetry is a 3D measurement technique, which uses central projection imaging as its fundamental mathematical model (Luhmann et al. 2011). From photographs, shot from different perspectives, ray bundles are produced to define the object's contours. The location of the intercept point of at least two ray bundles (from two photographs) of the same object point defines its location in space. By using multiple images, a model of rock surfaces can be produced. In the laboratory a fixed setup with known dimensions between the object and the camera was applied. A tripod and turntable were used. In order to evaluate if the method can be used in the field, for comparison the images were gathered free hand as well.

For the construction of the surfaces from the images the open-source software VisualSFM (e.g. Wu 2013) was used. Varying camera settings such as resolution, auto-focus settings and iso-value were tested. No marked effects under lab-conditions were seen, so that for convenience the cameras automatically set the settings. This holds for both types of camera used, being a Pentax reflex camera and a simple Rollei digital camera.

As a reference for the above-mentioned procedure the surfaces were also measured with a GOM Atos I white light strip scanner. With this device, an accuracy of approximately 0.04 mm can be achieved. A similar device was successfully used in the past for rock surfaces (Tatone & Grasselli 2013).

The produced point clouds were then edited with Meshlab. Rough errors were visually identified and removed, e.g. points lying obviously too far away from the surface. The point clouds were then scaled and realigned to the same orientation and location in space.

GNU Octave was applied to construct the surfaces from the point clouds by linear interpolation onto regular grids. This technique permits the comparison of the different datasets since all profiles fit exactly onto each other. Within this software environment, the roughness parameters were calculated.

3 ROUGHNESS PARAMETER

Roughness parameters can be defined in 3D or as simple profile parameters. There exists a wide range of different approaches. For example Belem et al. (2000) looked at the inclination angles of the elementary cells of the grid.

Instead, the widely used JRC is a profile parameter. As the most simple way, the JRC is defined visually by comparison of the surface in question with standard profiles (Barton & Choubey 1977). Tilt tests can also be conducted. Tse & Cruden (1979) introduced an objective calculation method of the JRC. From the square root of the sum of the squared differences of adjacent height coordinates divided by the number of equal intervals and the squared sampling step the parameter Z2 is defined (Equation 1).

$$2 = \sqrt{\frac{1}{\bullet(\quad)} \quad (\quad - \quad)} \tag{1}$$

The JRC is correlated with the Z2 value of the standard profiles (Equation 2).

$$= 32.2 + 32.47\ (\log 2) \tag{2}$$

In the present study the correlation from Tatone & Grasselli (2010) was used because it considers the sampling step of the profile (Equation 3 and 4).

$$= 51.85 (\bullet 2)^{\cdot} - 10.37\ (0.5 \qquad\qquad) \tag{3}$$

$$= 55.03(\bullet\ 2)\ \cdot\ - 6.10\ (1.0\ \qquad\qquad)\qquad (4)$$

4 RESULTS

For the study, five rock samples from different lithologies, namely shale, rhyolite, gabbro, granite and sandstone, were used. They varied from slickensided smooth (shale) to rough (granite). For evaluation in this context, the rhyolite and sandstone sample are chosen. Sampling steps of 0.5 mm were used for the grids resulting in varying amounts of profiles (depending on the sample size) of up to 1400.

In Figure 1 the difference in topography between the Atos I scan and the photogrammetric dataset is shown. The two surfaces obviously resemble each other in appearance. However, the photogrammetric surface shows more topographic features. It is more disturbed than the Atos I scan. This can be explained by the higher noise level in the photogrammetric data.

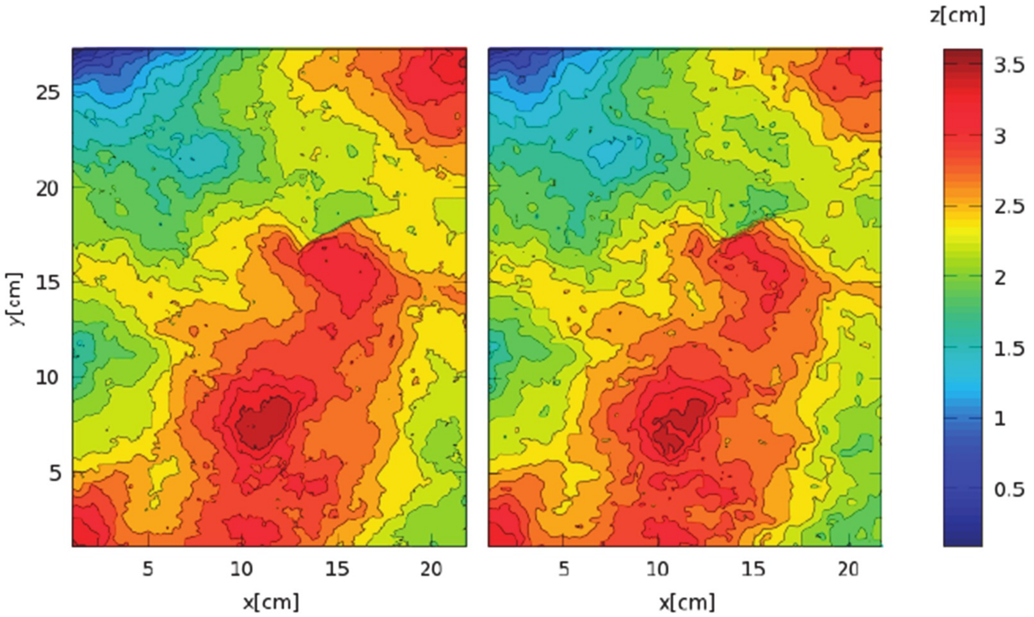

Figure 1. Topography of rhyolite sample, left: Atos I (ref.), right: photogrammetry.

The noise level had no significant effect on the calculated JRC values for the rhyolite sample. This can be seen in Figure 2. There, different histograms of the JRC for varying camera settings and the 520 profiles are shown. The dataset, from which Figure 1 resulted, is colored blue (upward facing triangles). It becomes clear, that defining one single JRC value for the surface is not sufficient. The majority of the JRC values for the 520 profiles lie in a span between 4 and 16 with a clear peak in the class JRC 8-9. Due to the plenty of 3D data the heterogeneity of the sample surface is visible. The mean value of the JRC is of 9.8 for the reference and 9.6 for the photogrammetric data set (blue colored dataset).

By default, in the field the JRC is determined with a contour gauge. Therefore, the datasets were compared with two perpendicular, manually produced exemplary profiles per sample. In Figure 3 the results are shown for the rhyolite sample. Because of a smaller sampling step of 1.0 mm the contour gauge was not able to capture the micro-roughness. The photogrammetric data fits the reference scan very well. This is not the case for the sandstone sample, which is shown in Figure 4. For the plateau in x-direction between 13 and 18 cm on the profile, the photogrammetric line shows much higher fluctuation. This is also the case for the profile in y-direction where the peaks (micro-roughness) of the undulating profile are much more pronounced. The presence of mica pads on the surface of the sandstone resulted in light reflections, which disturbed the photogrammetric reconstruction. These problems were not seen in the white light strip ATOS scans since, with this method, the samples are actively illuminated. Additionally, due to the undulation of the surface and the low density of data points, smoothing produced too much leveling of the profile. Therefore, the photogrammetric profile in Figure 4 has to be considered as “raw”.

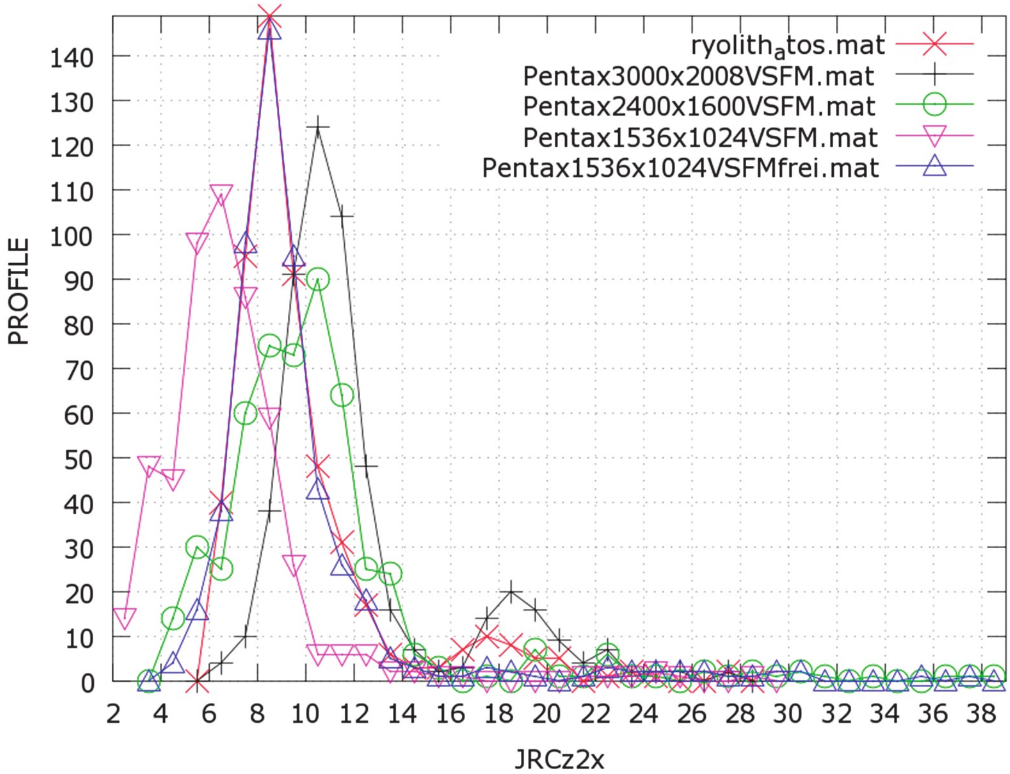

Figure 2. Histogram of JRC from Z2 in x-direction for rhyolite sample (520 profiles).

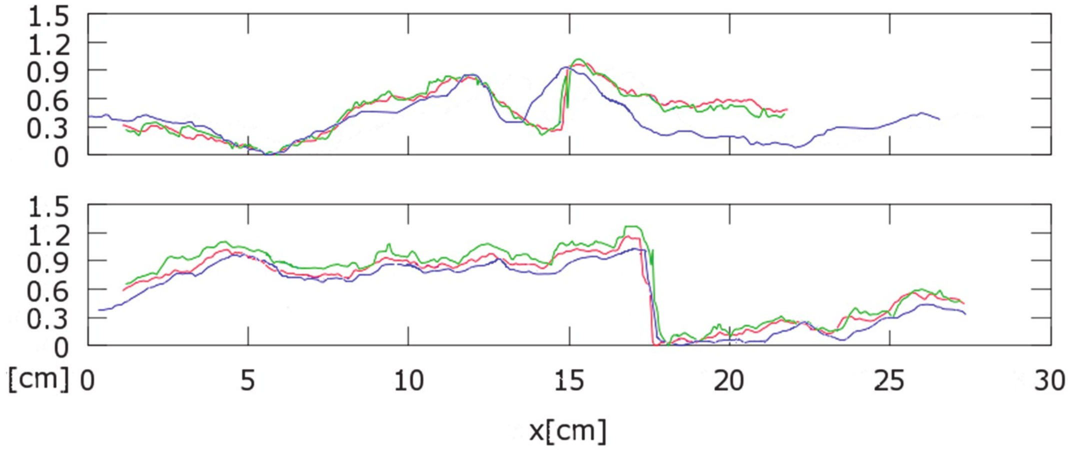

Figure 3. Exemplary roughness profiles rhyolite, top: in x-direction, bottom: in y-direction, blue: contour gauge, red: Atos I (ref.), green: photogrammetry.

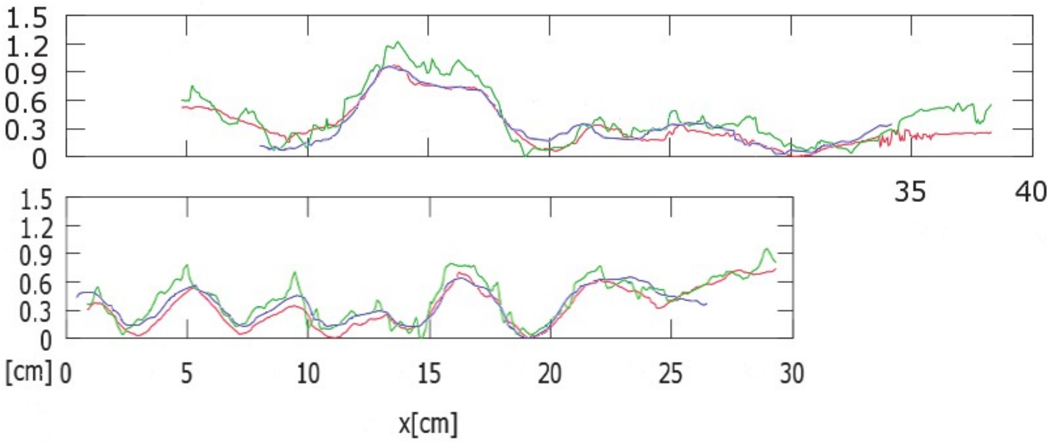

Figure 4. Exemplary roughness profiles sandstone, top: in x-direction, bottom: in y-direction, blue: contour gauge, red: Atos I (ref.), green: photogrammetry.

In Table 1 the JRC values for all exemplary profiles (including Figures 3 and 4) are listed. For the roughness profiles of the sandstone, the impression of higher roughness of the photogrammetry is confirmed, since the values differ greatly. Despite the visual agreement of the profiles, the JRC of the rhyolite also differed in the same magnitude. For the gabbro sample, a good agreement was achieved. The roughness of granite was clearly underestimated. Most important the JRC exceeded the from Barton & Choubey (1977) established roughness classes. This is due to the calculation according to Equation 3 and 4, which allow for higher values than 20. The calculated JRC of the shale sample underlined the problems with the equations, where negative values occurred. They are mathematically right but the question of physical eligibility has to be posed.

For the 10 profiles that were compared, it was seen that for smooth surfaces the JRC was higher than the reference value, for rough surfaces it was lower when photogrammetry was applied. Additionally, by using a contour gauge it was less likely to overestimate roughness. Except for two profiles where the roughness was close to the reference, the gauge yielded lower values.

Table 1. JRC for the exemplary profiles from the 3 different measuring procedures, x=x-direction, y=y-direction.

Profile	Atos I	Photogrammetry	Contour gauge
Rhyolite x	19.3	25.0	13.1
Rhyolite y	26.5	30.2	18.6
Sandstone x	16.3	22.7	10.3
Sandstone y	10.7	22.8	12.4
Shale x	-4.6	-1.1	-3.2
Shale y	-4.5	-1.8	0.7
Granite x	30.4	22.2	19.7
Granite y	19.8	11.9	21.2
Gabbro x	16.6	16.1	13.3
Gabbro y	9.5	10.5	10.3

5 CONCLUSION

Five different rock surfaces of varying roughness were measured. The SFM algorithms could describe the overall topography successfully. In terms of roughness the results differed notably. Four out of five samples exhibited higher roughness than the reference. Only for the very rough granite, roughness was underestimated. The comparison of profiles included measurements with a contour gauge being the method used by default. The determined roughness values were reasonable. In principle, the open-source photogrammetry software used is appropriate for mapping rock surface roughness, but only for very rough surfaces, sufficient accuracy was achieved. Problems were seen with reflecting minerals on surfaces. Due to the noise in the photogrammetric data, smoothing was needed. The algorithms applied worked well with on the micro-scale already rough surfaces but failed with samples of high macro-roughness and low-micro roughness (rhythmic, undulating sandstone). Therefore, the noise-level and data smoothing have to be improved.

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