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Rock surface roughness measurement using CSI technique and analysis of surface characterization by qualitative and quantitative results

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Abstract. In order to develop image processing that is widely used in geo-processing and analysis, we introduce an alternative technique for the characterization of rock samples. The technique that we have used for characterizing inhomogeneous surfaces is based on Coherence Scanning Interferometry (CSI). An optical probe is first used to scan over the depth of the surface roughness of the sample. Then, to analyse the measured fringe data, we use the Five Sample Adaptive method to obtain quantitative results of the surface shape. To analyse the surface roughness parameters, H_{mm} and R_q, a new window resizing analysis technique is employed. The results of the morphology and surface roughness analysis show micron and nano-scale information which is characteristic of each rock type and its history. These could be used for mineral identification and studies in rock movement on different surfaces. Image processing is thus used to define the physical parameters of the rock surface.

1. Introduction

The surface analysis of rocks is necessary in order to be able to define their physical parameters, such as for instance the surface roughness that can be measured by microscopy to give information not only about the rock surface texture but also on its porosity. Various techniques that have been used to obtain images of rock surfaces are conventional optical microscopy, electron microscopy such as scanning electron microscopy (SEM), atomic force microscopy (AFM), etc. The results of image measurements using conventional optical microscopy is on the micro-metre scale and for SEM it is up to the nano-scale.

CSI, or white light scanning interferometry (WSLI), or Coherence Probe Microscopy (CPM) as it also known, is an increasingly popular method for measuring the roughness and shape of microscopic surfaces. The technique consists of a fast, non-contacting method for measuring surfaces that is increasingly important as a means of examining not only material surfaces but also components such as miniature optical elements, micro-fluidic devices and micro-electro-mechanical systems. It combines the axial resolution of an interferometer and the lateral resolution of a high-magnification optical microscope; commercial instruments are now an integral part of most research laboratories [1-4].

Most real surfaces are smooth surfaces which have higher self-affinity. They can be treated as fractals under well-defined spatial limits, so that within these limits specific statistical properties upon scale change are preserved by the surface morphology. In this case, they can be auto-scaled [5,6]. Fractals can be characterized by self-affinity, an example of these in nature being trees, leaves, clouds, and rocks. Self-affinity occurs when the fractals are not exact copies of themselves but there is still preservation of the general shape with more than one transformation and the need for a scale reduction for morphology invariance [5,7]. According to Peitgen et al. [5,8], one of the most common methods that is used to calculate the fractal dimension is the box counting method or what we call in this paper, the window resizing technique.

2. Coherence Scanning Interferometry (CSI) Technique

CSI is an important optical technique that is now widely used in the measurement of surface roughness and microscopic surface shape. CSI has the advantages of being rapid, non-destructive and applicable to many different types of surfaces. The technique makes use of a series of white light fringes superimposed on an image of the sample on the camera target, the central fringe along the optical axis corresponding to the position of the surface. The fringes are scanned over the whole depth of the sample surface by modifying the distance between the objective and the sample. A series of images is acquired with a camera at regular intervals to give a stack of XYZ images and using signal processing along the z-axis the peak of the fringe envelope is determined at each pixel and thus the corresponding height of the surface at each point in the image [9].

The system developed at ICube is shown in figure 1, based on a modified Leitz-Linnik microscope equipped with two 50× objectives and an incandescent lamp (centered at a wavelength of 580 nm), giving a lateral optical resolution of 0.42 µm with a CCD camera Basler-AVA 1000, and using a piezo scanner (PIFOC from PI) for vertical scanning. The computer specification is Processor Intel® Xeon® CPU 2.33 GHz RAM 8G.

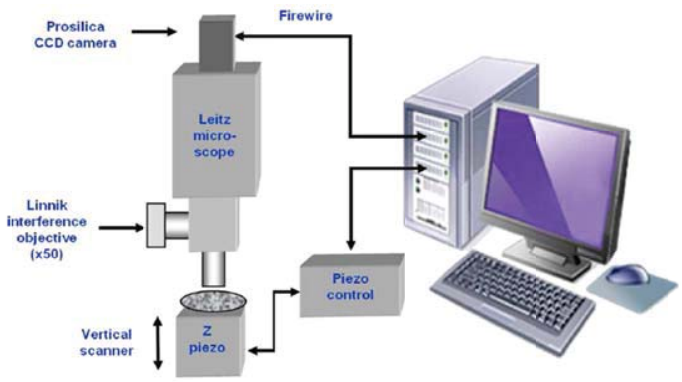


Figure 1. CSI instrument developed at ICube [10]

3. Analysis Methods

3.1. *Five sample adaptive (FSA)*

The FSA method (fringe visibility method proposed by Larkin [11]) is used to determine the fringe envelope and the surface height. This method detects the envelope of fringe signals by using five sampling positions along the optical axis. For each sampling position on the envelope, the amplitude value is calculated from the local position and four neighbouring sampling positions. The calculated envelope is given by:

$$4\,\mathrm{A}^2 \sin^4 \varphi = (\mathrm{I}_2 - \mathrm{I}_4)^2 - (\mathrm{I}_1 - \mathrm{I}_3)(\mathrm{I}_3 - \mathrm{I}_5) \quad (1)$$

where A is the amplitude value on one sampling position; φ is phase shift due to scanning step; I_3 is the local position; I_1, I_2, I_4, I_5 are the neighboring sampling positions.
For values of φ close to 90°, the equation (1) can be written as:

$$\mathrm{A}^2 = \frac{1}{4}[(\mathrm{I}_2 - \mathrm{I}_4)^2(\mathrm{I}_1 - \mathrm{I}_3)(\mathrm{I}_3 - \mathrm{I}_5)] \quad (2)$$

The amplitude value of the envelope A can be calculated by only two multiplications and one square root operation. This gives the advantage in time computation. However, the FSA algorithm requires the values of φ to be close to 90°, for accurate measurement.

3.2. Window resizing technique

In order to analyse the roughness data quantitatively, we used the window resizing technique to give the roughness amplitude parameters, H_{mm} or the peak-valley roughness and R_q or the root mean square (RMS) value of the roughness as a function of window size. The roughness calculation is then conducted on the cell. The number of squares depend on the value of δ, where $\delta = 1, 2, 3, \cdots, mod(n/2)$ where n is a pixel size in 1D. This is called a geometrical series and is written as:

$$\text{window size} = 2^{\delta+1} \text{ squares} \quad (3)$$

The cell has the shape of a square, where $\partial x = \partial y$. Window resizing calculates the roughness values at a given cell size over the whole of the image arithmetically.

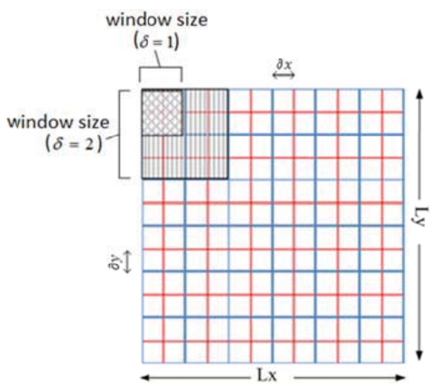


Figure 2. Composition of one cell consisting of four squares for $\boldsymbol{\delta = 1}$

We use the formula in equation (4) to calculate H_{mm} and equation (6) to calculate R_q [12]

$$H_{mm}(\delta) = \frac{1}{(i_{max}-2\delta)(j_{max}-2\delta)} \sum_{i=1+\delta}^{i_{max}-\delta} \sum_{j=1+\delta}^{j_{max}-\delta} (z_{max} - z_{min})_{i,j} \quad (4)$$

where

$$(z_{max})i,j = Max(z_{n,m}), n \in [i-\delta, i+\delta], m \in [j-\delta, j+\delta]$$
$$(z_{min})i,j = Min(z_{n,m}), n \in [i-\delta, i+\delta], m \in [j-\delta, j+\delta] \quad (5)$$

$$R_q(\delta) = H_{rms}(\delta) = \frac{1}{(i_{max}-2\delta)(j_{max}-2\delta)} \sum_{i=1+\delta}^{i_{max}-\delta} \sum_{j=1+\delta}^{j_{max}-\delta} \sqrt{\langle (z-\overline{z})^2 \rangle_{i,j}} \quad (6)$$

and

$$\langle (z-\overline{z})^2 \rangle_{i,j} = \frac{1}{(1+2\delta)^2} \sum_{n=i-\delta} \sum_{m=j-\delta} \left(z_{n,m} - \overline{z}\right)^2 \quad (7)$$

With:

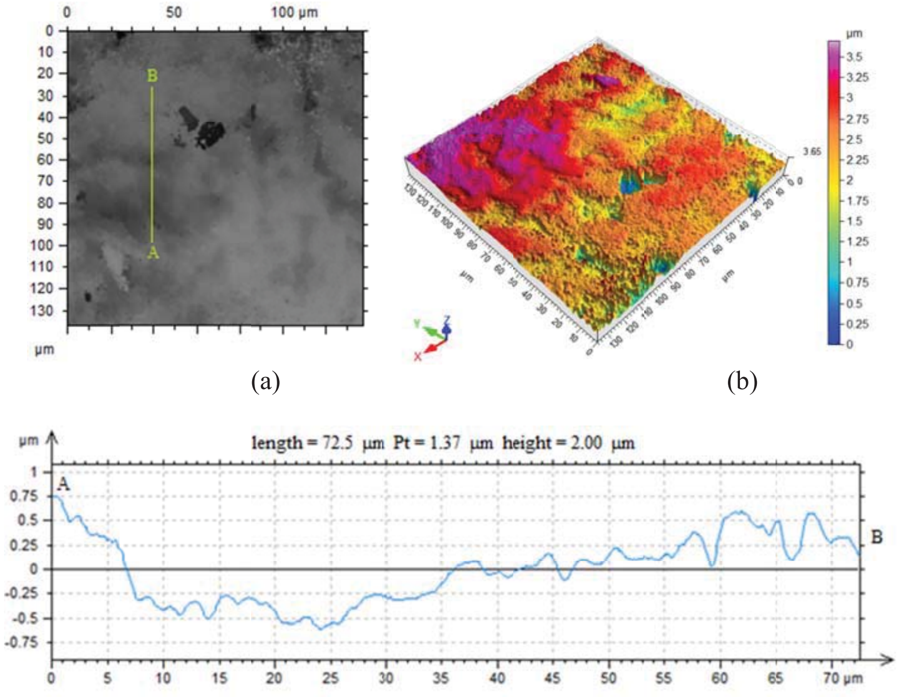
$$(\overline{z})_{i,j} = \langle z \rangle_{i,j} = \frac{1}{(1+2\delta)^2} \sum_{n=i-\delta}^{1+\delta} \sum_{m=j-\delta}^{j+\delta} z_{n,m} \quad (8)$$

4. Results : Surface Characterization

Two types of limestone, marble limestone and hematite limestone, were used as samples in order to test the CSI method. These stones have very fine and smooth surface because of their self-affinity character. A coating treatment process was not necessary for each sample as in the case of SEM measurement, which means that using the CSI method, the samples are not damaged. Results of CSI roughness measurement are presented in size dimension of 1024×1024 [pixel size dx = 0.13 µm].

4.1. Results of sample marble limestone

Figure 3 shows a gray scale height image in (a) and a 3D altitude distribution in (b). A line profile A-B from (a) is shown in (c).

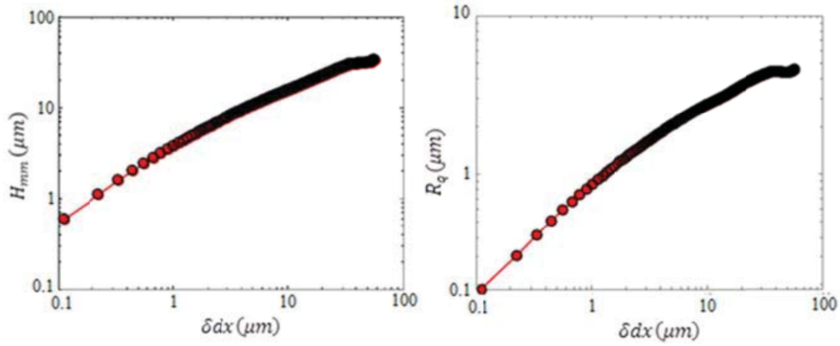


(a) (b)

(c)

Figure 3. Marble limestone roughness measured by CSI: (a) gray level height image (b) 3D altitude distribution (c) line profile along line A to B from (a)

The calculation result of the roughness distribution according to window size is shown in figure 4 based on the image in figure 3(c).

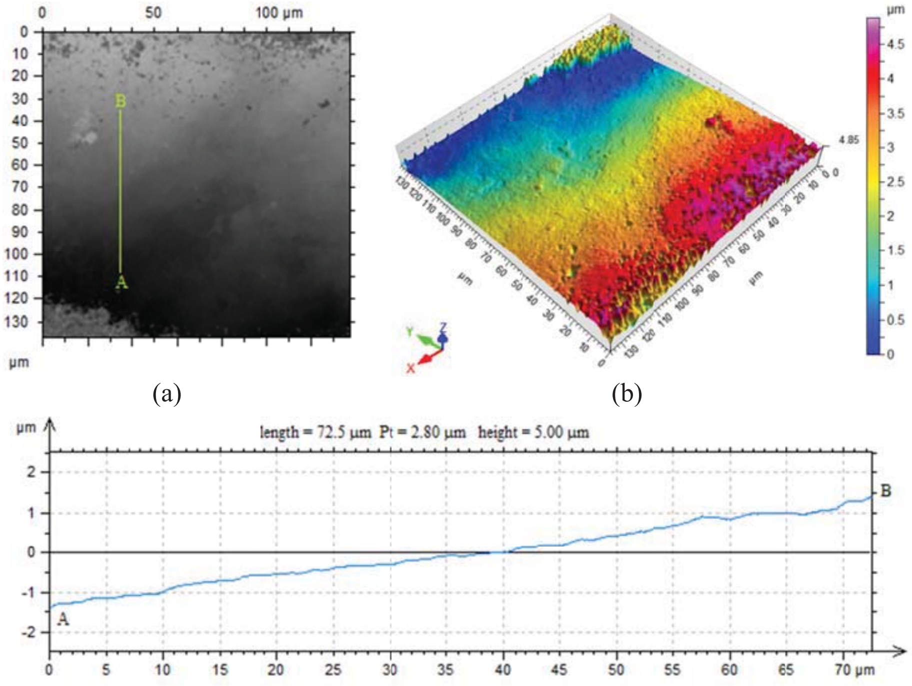


(a) (b)

Figure 4. Result of window resizing analysis for marble limestone surface rock (a) peak-valley roughness (b) RMS roughness

4.2. Result of sample hematite limestone

Figure 5 shows a gray scale height image in (a) and a 3D altitude distribution in (b). A line profile A-B from (a) is shown in (c).

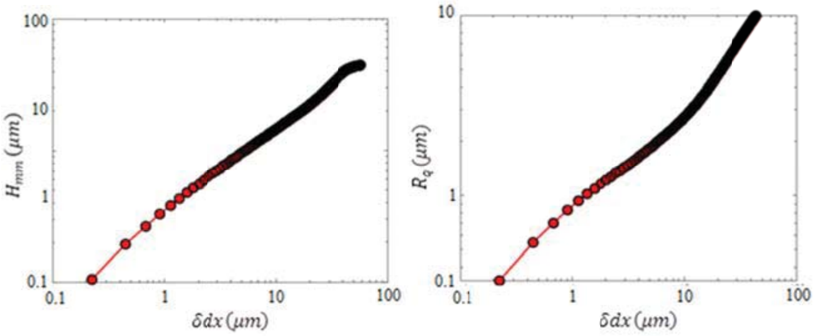


(a) (b)

(c)

Figure 5. Hematite limestone measured by CSI (a) gray level image (b) altitude distribution (c) line profile A-B from (a)

This image shows fine texture, and is smoother than the sample in figure 3. The line profile presented in figure 5 shows little microstructure. The calculation result of the roughness distribution according to window size is shown in figure 6 based on the image in figure 5(a).



(a) (b)

Figure 6. Result of window resizing analysis for hematite limestone surface rock (a) peak-valley roughness (b) RMS roughness

Conclusion

The CSI technique can be used to quantitatively measure the surface roughness of rock sample surfaces. Image processing can thus be used to define the physical parameters of the rock surface. In future work, the analysis of the results of the images from the CSI technique could be used for mineral identification and to study the link between surface roughness and the movement of rocks on different types of surfaces in the study of landslides.

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