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# SIMULATION OF THE OBSERVED IMAGE ON A RELIEF : NOTION OF TRANSFER FUNCTION

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## ABSTRACT

To analyze non planar surfaces or reliefs, one can use stereoscopic or confocal methods. In this paper, we present another method based on scanning electron images and on the knowledge of the transfer function. This function can be estimated and modelled. Good agreements have been obtained on simulated images.

**Key words** : relief, non planar surfaces, modelling, transfer function, SEM image, surface area.

## INTRODUCTION

The surface roughness is the most common parameter defined to characterize non planar surfaces (NPS) like fracture surfaces, skin or steel sheets. A non planar surface can be considered as a relief where a point $P_i$ of this relief is defined by 3 coordinates, $x_i$ and $y_i$ in the basic plane and $z_i$ the altitude. To obtain this relief two ways are possible : the first one corresponds to stereoscopic methods (two tilted images in scanning electron microscopy (Beucher & Hersant, 1979 ; Beucher, 1990) or epipolar geometry with two cameras for the macroscopic domain (Berger, 1992 ; Quiguer, 1992). The second way uses specific equipments like confocal microscopes or 3D roughness apparatus.

By using stereoscopic methods, one must obtain a pair of homologous pixels for each image. Only few pixels can be correlated by semi-automatic or automatic methods to obtain their altitude. In these conditions it is difficult to reconstruct the relief with accuracy.

The second way seems better as the relief is obtained directly. But, confocal microscopes have a spatial resolution limited to 0.2 μm and the 3D roughness apparatus of about 1 μm.

These systems are not well adapted to analyze the roughness of fracture surfaces or simular surfaces. To characterize these surfaces, one suggests a third way : the use of pseudo-relief images obtained by scanning electron microscopy. That is the scope of this paper.

## THE IMAGE FORMATION IN SEM

The scanning electron microscopy (SEM) image is due to the interaction between incident electron beam and the surface of the analysed material. Two main kinds of images are obtained :

- backscattered electron images (BEI),
- secondary electron images (SEI).

For the backscattered electron mode, the contrast of the image is due to the surface orientation according to the direction of the incident beam (it is a topographic image) and to the difference between atomic numbers in materials (composition image).

For secondary electron images, one obtains topographic images only.

The two kinds of topographic images are different because the secondary electron energy is much lower than the backscattered electron energy. The trajectory of the backscattered electrons is straight and so, all the parts of a surface cannot be seen by one detector system whereas the secondary electron trajectory is curved and gives an information for all the parts of a surface.

But practically, some parts can be regarded as unknown because the signal to noise ratio is very low. These parts correspond to deep cavities in the material.

If one considers a non planar surface represented by a function f, the topographic image obtained by SEM is a "pseudo-relief" defined by the function g. These two functions are related by means of a transfer function T, with :

$$g = T(f) \qquad (1)$$

It is impossible to know this transfer function because this function depends on several "parameters". The angle between the surface and the incident beam is the main one. Moreover one must also take into account edges and tips effects which cannot be translated by mathematical equations.

That is the reason why it is impossible to quantify the true surface by absolute parameters from topographic image. But, if one assumes that the transfer function verifies the mathematically increasing property, it is possible to classify different surfaces thanks to roughness or other parameters. Indeed if :

$$f_1 > f_2 \qquad (2)$$

then :

$$T(f_1) > T(f_2) \text{ or } g_1 > g_2 \qquad (3)$$

and reciprocally.

## MODELLING OF THE TRANSFER FUNCTION AND OF SURFACES

The true transfer function giving a perspective effect is modelled in a simple way by considering $\theta$ as the angle between the surface and the incident beam and $\theta'$ the angle between the detector and the reflected beam. One assumes that the intensity is proportional to $\cos\theta \cos\theta'$ if $0 < \theta < 90°$ (all other intensities are equal to zero as they correspond to black zones).

By using this simple transfer function, one must obtain an image from a simulated surface, which can be compared to real topographic images.

To test this transfer function, boolean functions were used (Jeulin, 1991). These probabilistic functions are defined by $\lambda$, the Poisson density, and by the primary function corresponding to a Poisson distribution of spheres (Fig. 1). Through this way, it is possible to construct several reliefs.

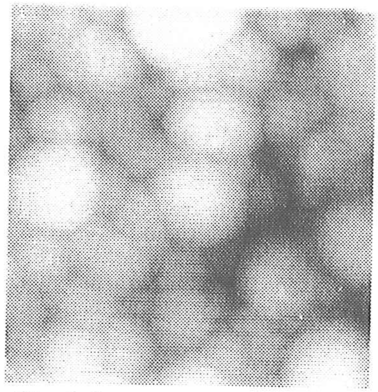

Figure 1 : Simulated image of a boolean surface.

In an orthonormal reference $(\vec{i},\vec{j},\vec{k})$, the four pixels meighbouring the current pixel $P_0$ $(x_0, y_0, z_0)$ define a basal medium plane (Fig. 2). In digital space, with a pixel distance equal to one, their coordinates are:

$$P_1\begin{cases} x_1 = x_0 \\ y_1 = y_0 + 1 \\ z_1 \end{cases} \quad P_2\begin{cases} x_2 = x_0 + 1 \\ y_2 = y_0 \\ z_2 \end{cases} \quad P_3\begin{cases} x_3 = x_0 \\ y_3 = y_0 - 1 \\ z_3 \end{cases} \quad P_4\begin{cases} x_4 = x_0 - 1 \\ y_4 = y_0 \\ z_4 \end{cases} \qquad (4)$$

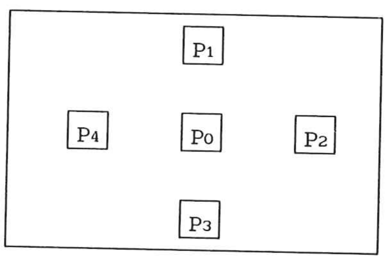


Figure 2 : Neighbourhood of a pixel $P_0$.

The coefficients of the equation of the plane :

$$Ax + By + Cz + D = 0$$

defined by two vectors $\vec{V_v} = \overrightarrow{P_3P_1}$ and $\vec{V_h} = \overrightarrow{P_4P_2}$, are given by :

$$\begin{cases} A = -(z_2 - z_4) = -Z_h \\ B = -(z_1 - z_3) = -Z_v \\ C = +2 \\ D = +Z_h x_0 + Z_v Y_0 - 2z_0 \end{cases}$$

It must be noted that in the following D has no influence in the next equations.

From the data, one determines the vector $\vec{G}$ normal to the plane and defined by $(- Z_h, - Z_v, 2)$.

If $\vec{H}$ is the vector (a,b,c) corresponding to the incident beam, one has :

$$\cos\theta = \frac{- a Z_h - bZ_v + 2c}{\sqrt{Z_h^2 + Z_v^2 + 4}\ \sqrt{a^2+b^2+c^2}} \qquad (5)$$

In the simulation, this corresponds to the intensity of the reflected signal when the intensity of the incident signal is equal to one. If the detector is perpendicular to the basic plane (0,0,1), the intensity of the collected signal is proportional to the cosinus θ' of the angle between the direction of the detector and of the one of the reflected signal :

$$\cos \theta' = \frac{2}{\sqrt{Z_h^2 + Z_v^2 + 4}} \qquad (6)$$

So, the radiometric value of a pixel, with an incident intensity equal to 255 is :

$$z = 255 \cos\theta \cos\theta' \text{ for } 0 \le \theta \le 90$$
$$\text{otherwise } z = 0 \qquad (7)$$

This value depends on the plane orientation but not on the altitude $z_0$ of the point $P_0$

Figure 1 presents the initial image and figures 3 and 4 the images modified by the transfer function with two incident angles. The aspects of these images are similar to real images.

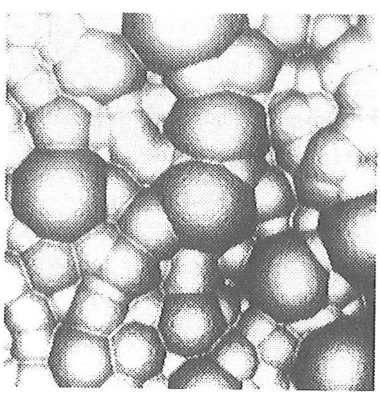

Figure 3 : Same image as figure 1, but tilted vertically.

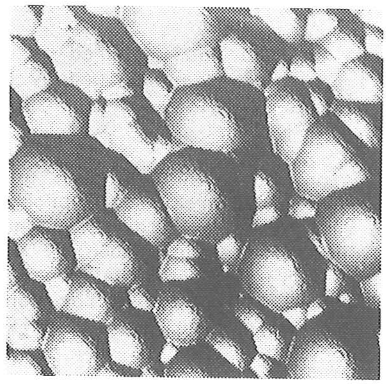

Figure 4 : Same image as figure 1, but tilted at 45°.

Table I : Change in the surface area with the lighting for different simulated structures.

| Mean hemisphere radius | Real surface area | Observed surface area | Observed surface area |
|---|---|---|---|
| lighting | | vertical | at 45° |
| pixel | $pixel^2$ | $pixel^2$ | $pixel^2$ |
| 5 | 87400 | 1491000 | 1401777 |
| 10 | 85000 | 994983 | 953269 |
| 15 | 82220 | 718858 | 698900 |
| 20 | 78500 | 525859 | 544800 |

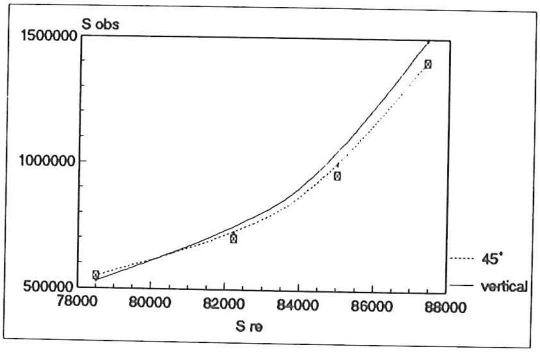


Figure 5 : Observed surface area, $S_{obs}$, as a function of real surface area, $sS_{re}$, (in $pixel^2$ unit).

## MEASURES ON SIMULATED IMAGES

On simulated images, the surface was measured by a triangulation method (Hénault, 1992). These images are characterized by the medium value of the hemisphere radius. The results are given in table I.

Figure 5 shows the evolution of the surface area of the transfer function, T(f), as a function of the surface area of the probabilistic model used for the "true" function for two angles of detector. Regular curves are obtained for each angle. Each curve can be described by a polynomial of the $3^{rd}$ order. The large values of T(f) surface area are due to the transfer function which increases the contrast like SEM for non planar surfaces. With this transfer function, increasing property is verified.

## CONCLUSION

We can conclude that it is possible to classify non planar surfaces if the real transfer function is similar to our modelled transfer function. So, the relative values of surface roughness can be estimated and a comparison between different surfaces can be performed by using the same SEM after standardization.

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