AGH Journal of Mining and Geoengineering • Vol. 36 • No. 1 • 2012

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DESCRIPTION OF THE FRACTURE PATH BY COMPUTER IMAGE ANALYSIS

1. Introduction

Image analysis has been used to extract relevant information from images in many areas of science and technology for many years. The aims of this study are to use image analysis to detect and describe the course of fractures in some crystalline rocks observed under an optical microscope. For this research we have defined two types of the cracks, which can occur in rock:

— the intercristalline crack (Fig. 1), where the fracture goes between two different grains,
— the trancrystalline crack (Fig. 2), where the fracture goes through one grain and halves it.

This kind of research has already been conducted in a non-automatic way [2, 5], but this type of study has been very time consuming.

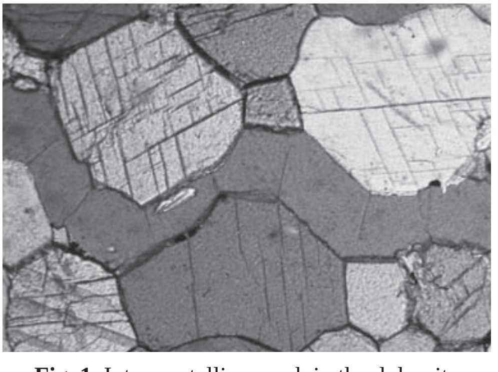

Fig. 1. Intercrystalline crack in the dolomite from Redziny

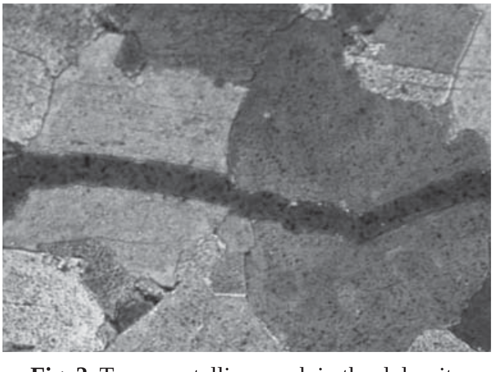

Fig. 2. Transcrystalline crack in the dolomite from Laskowa Gora

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Therefore, it is advisable to try to create an algorithm which will automatically determine the type of cracks in particular rock, based on microscopic images taken on their thin section.

This paper presents the algorithm, which may be used in such type of research.

2. The Material

The research was conducted on two types of rock: the sandstone from Wisniówka and the dolomite from Rędziny. Before the research began these rocks were tensile by using Brazilian test. In the reported studies, the Brazilian test was performed on the INSTRON 8500 Rock Testing Machine with a deformation speed of the specimen equal to 10^{-5} s^{-1}.

This test was carried out in such a way that the sample does not spread out, and after its completion sample could be impregnated in the glue. This allowed the microscopic observation of the fracture path. The research was conducted on images registered under the polarizing microscope on the rock thin sections.

3. The Algorithm

3.1. Initial operations

Images obtained during the shooting of the cracks observed on the thin section were subjected to pre-treatment aimed at eliminating image noise. For this purpose, the initial color image (Fig. 3) was divided into three components R, G and B. Each of these components has been subjected to median filtering. This filter was used because it usually does not cause deterioration of an object edge, and effectively eliminates all types of local noise [7]. Further parts of the algorithm can be divided into two stages. In the first stage the fracture is detected automatically. In the second stage, it is stated if the fracture runs in an intercristalline or trancrystalline way.

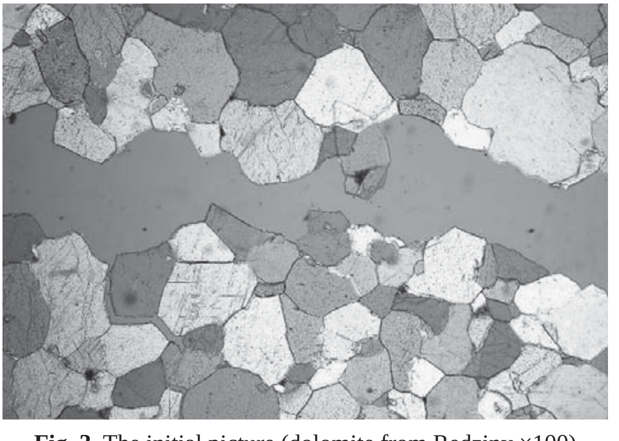

Fig. 3. The initial picture (dolomite from Redziny ×100)

3.2. Detection of the fracture

It was decided that the detection of the fracture would be based on the use of the watershed operation. This algorithm has been proposed by Beucher and Lantuejoul [1]. The idea of this algorithm is based on treating the image as a topographic map, for which the heights of the terrain was replaced by the grey level of pixels.

The algorithm starts to work in the local minima where the "area flooding" begins.

In each step of the algorithm, "water level" is increased by one gray level, which leads to further "area flooding". At a certain stage of the algorithm the catchment areas coming from two different local minima will meet together, and the place where this occurs is defined as a watershed line. Applying the watershed algorithm to crystalline rock images often leads to a correct detection of grain boundaries. For proper use of this method to detect the fracture, it is vital to set the mask image correctly as well as the marker image. Then, based on these images, the watershed algorithm is executed [4].

The first step taken to create an image of the mask is to determine the morphological gradient. The gradient is defined as the difference between the dilation and the erosion of the image. The gradient images were calculated for every RGB component of the initial image, and then, the result image was defined as a maximum of these gradients. The resulting image is the mask image (Fig. 4), and it is used in next algorithm's steps.

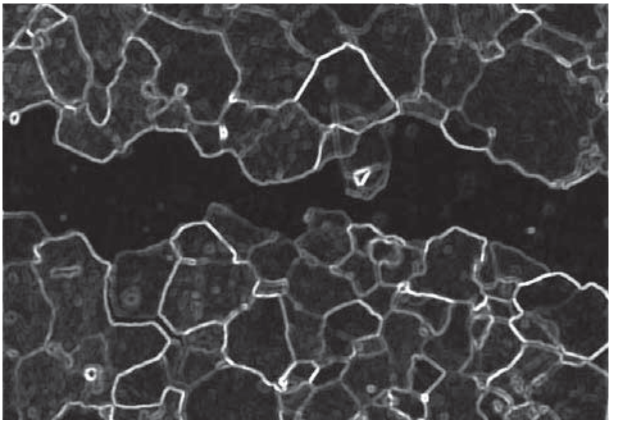

Fig. 4. The mask image

The next step of the algorithm was to create the marker image. This image was created based on the algorithm presented in the works [6] and [5].

In order to automatically obtain the marker image the mask image has been filtered to remove noise and then a method of extended minima was used. This method can be described by the following algorithm.

After formation of the image mask (Fig. 4) and the marker image (Fig. 5), the watershed algorithm was used. In this case, the method allows for the segmenting the image in a way,

ALGORITHM 1

Creating the marker image for the watershed operation

G’ = neg(G)	// the negative of the mask image (G)
O = G’ – d	// the subtraction of the constant *d* — so called the grayscale dynamics
RE → rec(O,G’)	// the reconstruction the image O into the image G’
W = G’ – RE	// the subtraction of the image RE from the image G’
WB = bin(W,0)	// the binarization of the image of W (threshold level = 0)
WB’ = neg(WB)	// the negative of the image (WB)
M = op_rec(WB’, s)	// the opening by the reconstruction of the image of WB’ (the circle in size S. The result is the marker image M)

which allows the distinguishing of the fracture. Due to the fact, that only the fracture was the object of the research we resigned from segmenting the grain boundaries. Thanks to that, the algorithm became simpler with. The grain segmentation methods applied to rock images we found in [5].

The last step in the algorithm is the identification of the fracture. It is possible to define the fracture by examining the length and the width of each segmented object, then the appointment of its elongation.

It was concluded that only large objects, with large elongation are the fractures or their fragments. It is important, to point, that the algorithm demands the orientation of the fracture be close to its level. Otherwise, the algorithm could define it wrongly. The final output of this part of the proposed algorithm is shown in Figure 6.

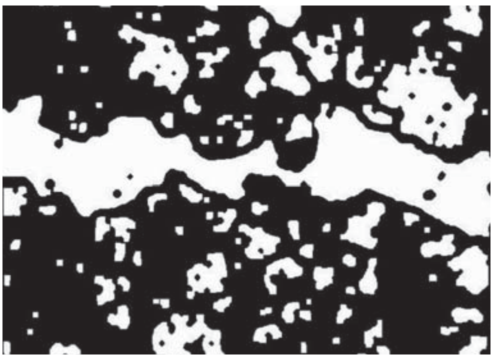

Fig. 5. The markers image

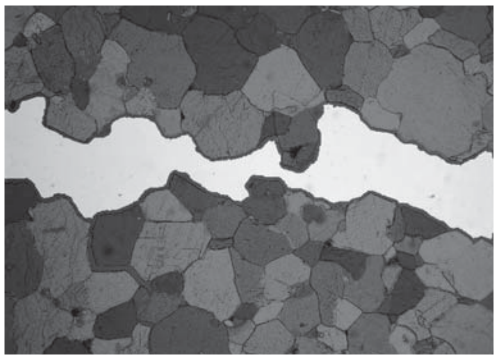

Fig. 6. Image with the segmented fracture

3.3. Determining the type of the fracture

After detecting the fracture, we begin the process of identification the type of crack. The part of the algorithm, which recognizes the type of fracture is based mainly on the so-called point operations. In the first stage, we put the image on a set of vertical lines, along which the analysis was performed. Figure 7 shows a demonstrative way, the set of such lines plotted on the image of the fracture. The distance between these lines may vary. In the studies, this distance was the smallest of the possible and was equal to 1 pixel. When the points of intersection of each line with the fracture were known, we defined two points (on each of these lines) which were situated in certain distance below and above the fracture. These points were the centres of small segments of the image. On the basis of the measurements made on them, the decision about the type of fracture was taken. The segments used in the researches had a size of 5×5 pixels (Fig. 8). Proposed decision process was based on work [3] and proceeds as follows.

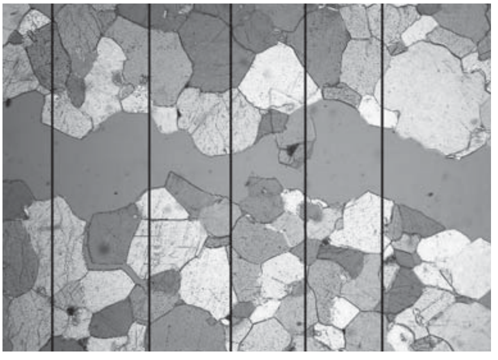

Fig. 7. The image of dolomite with a set of lines plotted on the segmented fracture

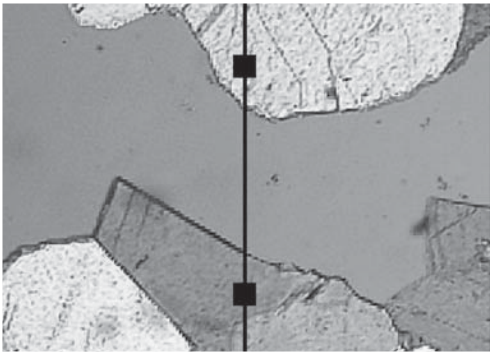

Fig. 8. Part of the image of dolomite marked by the segment

Firstly, we defined the boundary value σo. This value was the maximum standard deviation of the gray levels of pixels taken from the RGB components of the analyzed segment. As a precaution, when the standard deviation was more than σo, we assumed that the segment was not reliable and was not suitable for the decision-making process. This situation could appear for example when a section is on the boundary of two the grains, grains had a lot of inclusions, etc. The value σo was defined individually for every rock, based on preliminary measures.

Next, we defined the boundary value m. This was the value upon which the decision was taken on whether the test segments were on the same grain, or on two different grains. To take such a decision, the value of m was compared to the value of c, which was calculated as follows:

$$c = \max(cr, cg, cb) \tag{1}$$

where:

$$cr = |sr2 - sr1|, \quad cg = |sg2 - sg1|, \quad cb = |sb2 - sb1| \tag{2}$$

where:

- $sr1$, $sg1$, $sb1$ — the mean values of grey levels of the RGB components from the segment situated above the fracture,
- $sr2$, $sg2$, $sb2$ — the mean values of grey levels of the RGB components from the segment situated below the fracture.

After calculating the values of c, and after defining the value of m (this was made on the basis of preliminary measurements).

We assumed that if the value of c was smaller than the value of m, it meant that the two analyzed segments were on the two parts of the same grain, otherwise it was assumed that the segments were on two different grains.

Thanks to this, we obtained the information about the type of the fracture path.

4. Applications of the proposed method

The research was conducted for two types of rocks: dolomite from Rędziny and sandstone from Wisniówka. In the first phase of research thin sections of the dolomite and sandstone were photographed under a microscope at magnification of 10 and 20 times. For each rock we photographed seven areas which were placed along the fracture. On these pictures we made calculation based on the proposed algorithm.

The parameters we used in the algorithm in order to analyze the fracture in the dolomite from Rędzin were as follows:

— the median filtration was done by the mask 11×11,
— the dynamics d was equal to 11,
— the opening by reconstruction was done by means of the circle of size 13,
— boundary value of σ_o was equal to 0,05,
— boundary value of m was equal to 0,20.

Table 1 summarizes the results of the algorithm, for dolomite from Rędziny.

TABLE 1

The results of the algorithm's work for the dolomite from the Rędziny

Field no.	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**average**
intercrystalline crack [%]	46,57	41,01	39,12	53,13	50,75	38,74	48,52	45,15
transcrystalline crack [%]	53,43	58,99	60,88	46,87	49,25	61,26	51,48	54,85

The measurement results indicate that 45,15% of the fracture goes in an intercristalline way and 54,85% of the fracture goes in an trancristalline way. In the given case, the algorithm was not able to identify the type of fracture in about 19% of cases.

The second tested rock was the sandstone from Wisniówka (Fig. 9). The parameters that we used in the algorithm were as follows:

— the median filtration was done by the mask 13×13,
— the dynamics d was equal to 11,
— the opening by reconstruction was done by means of the circle of size 13,
— boundary value of σ_o was equal to 0,06,
— boundary value of m was equal to 0,25.

The segmented fracture of the sandstone from Wisniówka is presented in Figure 10.

Table 2 summarizes the results of the algorithm's work for the sandstone from Wisniówka. In this case we calculated that the 53.96% of cracks were trancrystalline and 46.04% — intercristalline. The algorithm did not identify the type of the crack in about 37% of cases.

TABLE 2
The results of the algorithm's work for the sandstone from Wisniówka

Field no.	1	2	3	4	5	6	7	average
intercrystalline crack [%]	48,97	48,29	34,72	41,92	35,48	39,95	64,71	46,04
transcrystalline crack [%]	51,03	51,71	65,28	58,08	64,52	60,05	35,29	53,96

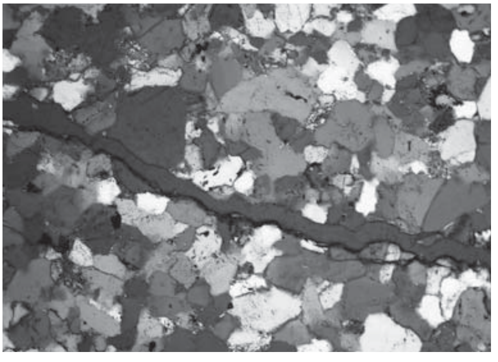

Fig. 9. The image of the sandstone from Wisniówka (×200)

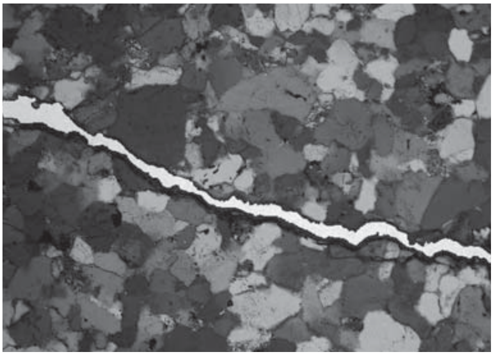

Fig. 10. The fracture detected on the image from Figure 9

5. Summary

The paper presents a method of the automation in the identification and measuring of the fracture path in the crystalline rocks. The lack of automation means this type of analysis will be rarely performed, as has been the case so far. This is due to the fact that they are burdensome and time consuming. Therefore, we believe that the automation of this research seems to be intentional. The paper proposes an algorithm which may be used for the full automation of these measurements. The results of the algorithm are satisfactory. A drawback of the method is the problems with crack detection when it is too narrow. This necessitates further improvements of the algorithm. Furthermore, the algorithm needs to be improved to eliminate the necessity of photographing the fracture only in the slope close to horizontal. Despite these remarks it should be noted that the algorithm works correctly. The very fact of measuring the course of the fracture in an automated way is a great achievement. After eliminating the aforementioned drawbacks, the algorithm could be used in geoengineering measurements. Despite these remarks, the algorithm works correctly. The results obtained from the automatic algorithm are similar to those obtained in a manual way (compare with [5]). Moreover, the possibility of doing this research automatically is a great achievement in computer automation and it might find use in the geo-engineering.

REFERENCES

[1] Beucher S., Lantuejoul C.: *Use of Watershed in Contour Detection*. Proceedings of the International Workshop on Image Processing. Real-Time Edge and Motion Detection/Estimation, Rennes, September 17–21, 1979.

[2] Bodziony J., Młynarczuk M., Ratajczak T.: *Identification of Trans- and Intercrystalline Image of the Fracture Surfaces of Rock Specimens.* Acta Stereol. Vol. 12, No. 2, 1993.

[3] Knapik A.: *Zastosowanie analizy obrazu do opisu przebiegu spękań w wybranych skałach obserwowanych pod mikroskopem optycznym*. Praca inżynierska — prom. M. Młynarczuk, AGH, Kraków 2011.

[4] Młynarczuk M.: *Zastosowanie automatycznej analizy obrazów w pomiarach struktur skał.* Materiały 27 Zimowej Szkoły Mechaniki Górotworu, 2004, s. 305–318.

[5] Młynarczuk M.: *Zastosowanie metod analizy obrazu i morfologii matematycznej do ilościowego opisu ukształtowania powierzchni przełamów skalnych.* Archives of Mining Sciences. Monografie, 3, 2008.

[6] Serra J., Młynarczuk M.: *Morphological Merging of Multidimensional Data*. Materiały konferencji STERMAT 2000. Kraków, 2000.

[7] Tadeusiewicz R., Korohoda P.: *Komputerowa analiza i przetwarzanie obrazów.* Wyd. Fundacji Postępu Telekomunikacji, Kraków, 1997.