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APPLICATION OF COMPUTER IMAGE ANALYSIS TO IMAGING AND ANALYSIS OF THE GRAINS IN 3D SPACE

1. Introduction

Nowadays, computer capabilities are very varied and commonly used, but still, in many fields they are undervalued or not applied in sufficient way. One such field, where computers can be applied in more sufficient way is geology and namely the topic connected with grain and structure measurements. These topics are important in rock and coal mining. Some parameters, especially spatial ones like volume, surface area or shape factors can be calculated using modern tools, based on 3D objects. Methods based on the spatial structure of the grain have been developed for many years, but still needs a lot of attention. In geological aspects, stereological methods are commonly used. They make it possible to get information about the grains spatial structure using the grains cross sections. The main disadvantage of this method is the fact, that it cannot be applied to a single object but it is a statistical method which needs a representative population of grains to get the correct parameters. Some stereological methods have also been developed which can focus on a single grain and are based on associated cross sections [3] or, so called, disector [2]. Unfortunately, those methods must be processed in cross sections which are placed very close to each other. For that reason, those methods are quite complicated when applied in geological and mineralogical issues. Based on this, and facing the problem, as a result of the research the authors proposed fresh glance at the creative grain measurement in 3D space method.

2. Data acquisition

Modern 3D imaging techniques are very helpful in the spatial description of grain structure. Devices which can be applied to this problem are varied 3D scanners, confocal micro-

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scopes, optical and laser profilometers and others [4]. The selection of exact device is mostly analyzing matter and it depends on size of analyzed objects. In the research described in this paper on optical profilometer utilizing white light MicroFrof MPR200 00 manufactured by FRT was used. Measured data contained information about grain heights seen from the top view. Values also contained a height value measuring table, on which grains were spilled. All the data was saved in 2D pixel array. Unfortunately, no information about grains bottom shape was available. Additionally, during measurements, some pixels were not measured due to limitations of the measuring device. It is typical situation in this kind of analysis and can be caused by the topography or reflexive feature of the grains surface. Pixels which were not properly measured, were reconstructed using kriging method. As the effect, a 3D XYZ voxel array describing top view spatial grains structure was obtained. The missing bottom shape data, which was unavailable for measuring head, were then reconstructed.

3. Data processing

Collected data was initially filtered and later the most important step of the analysis, which was the bottom shape reconstruction, proceeded. Reconstruction is based on the information about the highest and the smallest heights of the analyzed grains and information about heights was then placed on a circumference of the grain. On the basis of this information, the bottom part was reconstructed as a scaled mirror reflection of the top part of each grain.

The proposed bottom part reconstruction algorithm was created as modification of the method proposed in paper [5]. Description of the algorithm:

- In loop, over all the pixels, there were two vectors separated, horizontal and vertical, which was a member of the processed pixel.
- For both vectors it was found that the last non zero pixels which were the most remote and found to the left and right of the processed pixel.
- Afterwards, five pixels were separated (or less, if in the vector had less pixels) pixels in the direction, from the boundary pixel to processed one.
- Next, a mean value was computed from the two groups of pixels. Based on the two obtained values, an equation was evaluated regarding the line which crossed those two points.
- Based on the line equation, the minimum value of the pixel was computed as the mirror reflection across the obtained line in the same proportion as the proportion of the values created by the division of the highest pixel (in each vector) by the line.
- Using that algorithm, there were evaluated two minimum values (from two vectors) for every pixel, and from this two values was computed mean value. Obtained result was treated as the minimum value of the processed pixel.
- If height of the processed pixel was under the computed line and above half value of the highest pixel in vector, then minimum value was evaluated as mirror reflection based on half value of the highest pixel in vector. If height of the processed pixel was under the line and under the half value of the highest pixel in vector, then minimum value of processed pixel was not computed.

Obtained, in that way, a spatial image was applied in 3D algorithm of morphological filtering. In the case of the analysis of more grains, a spatial segmentation algorithm based on watershed transformation was applied [1] in order to separate connected grains.

4. Verification of the method

In order to verify the proposed method, the volume of three tests grains were evaluated using the proposed method, where commonly used methods are based on substitute diameters and actual volumes. Results of direct measurements are presented on figure 1. Result of 3D imaging of exemplary grain is presented on figure 2. The substitute diameters were defined as:

- the diameter of the sphere, which has the same surface area of projection as analyzed grain (projection diameter);
- arithmetic mean of length, width and height of the analyzed grain (arithmetic diameter);
- geometric mean of the three dimensions of the analyzed grain (geometric diameter);
- harmonic mean of the three dimensions of the analyzed grain (harmonic diameter).

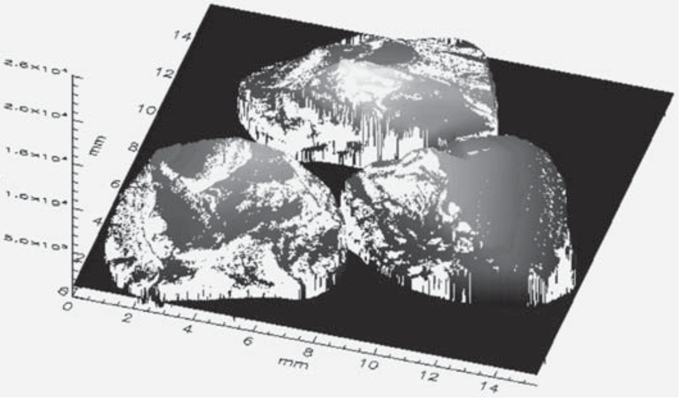

Fig. 1. Test grains, scanned by optical profilometer (white parts are immeasurable)

Additionally, to verify accuracy of those methods, the actual grains volumes were measured using a pycnometer. The obtained results, and percentage deviation from actual values are presented in table 1. Percentage deviation is also presented on figure 3.

5. Coal grain analysis

The subject of this research were coal grains. Collected samples were milled and sieved. As a result a grain class of over 1 mm was obtained. Grains were measured using an optical profilometer (Fig. 4). The algorithm applied for grains bottom part reconstruction was described in this paper in section 'Data processing'. Each grain was processed

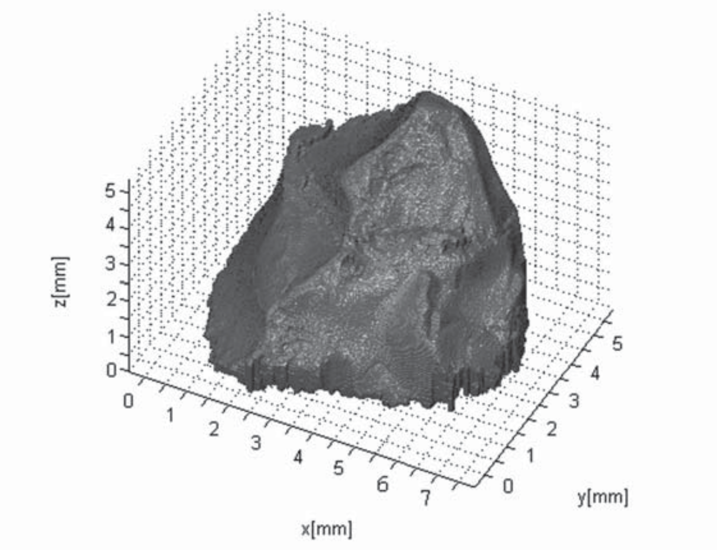

Fig. 2. Exemplary test grain reconstructed in 3D space

TABLE 1
Results of the measurement

Grain	Volume evaluated as:										
	Real values	3D analysis		Projection diameter		Arithmetic diameter		Geometric diameter		Harmonic diameter	
	V [mm^3]	V [mm^3]	%	V [mm^3]	%	V [mm^3]	%	V [mm^3]	%	V [mm^3]	%
1	142.0	121.3	14.58	185.4	30.56	181.0	27.46	175.8	23.80	171.2	20.56
2	105.3	93.40	11.30	177.5	68.57	179.3	70.28	177.5	68.57	175.7	66.86
3	125.7	105.7	15.91	188.3	49.80	203.7	62.05	203.5	61.89	203.4	61.81

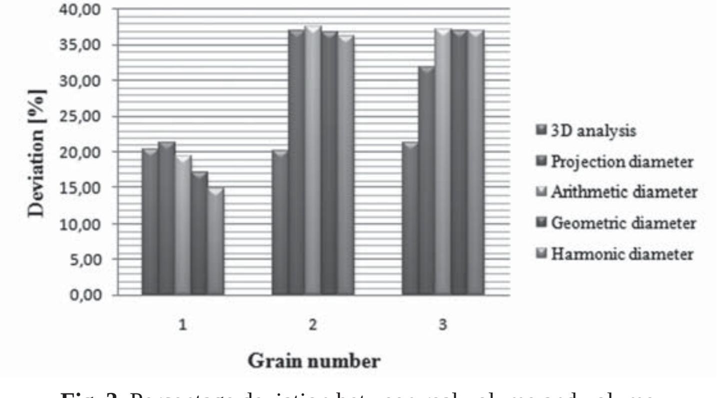

Fig. 3. Percentage deviation between real volume and volume evaluated using described methods

separately and its structure reconstructed individually. To achieve this goal, firstly all the objects on the flat image were labeled. Next, in a loop over all of the objects was applied and a reconstruction algorithm was applied and from this data was obtained and stored in 3D array.

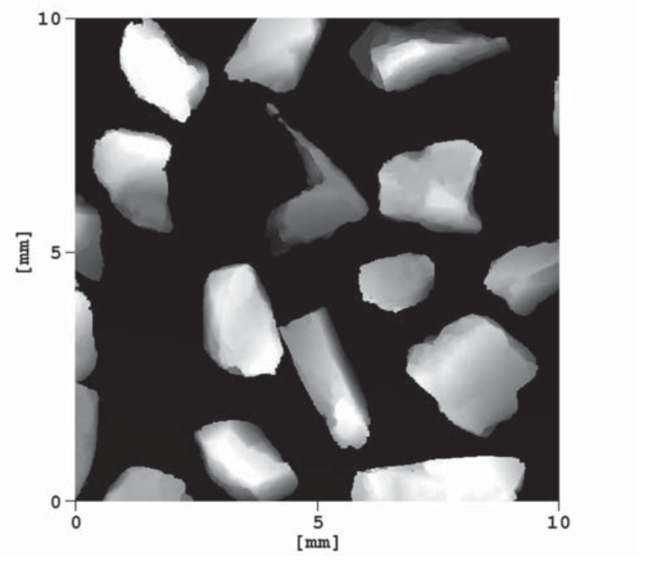

Fig. 4. Data obtained from optical profilometer (sample L10) represented as grayscale bitmap

After a successful reconstruction in 3D space, in order to erase possible noise, a 3D morphological filtration algorithm was applied: morphological opening followed by morphological closing. It is easily noticeable, that a grain after filtration is smooth and its surface is more similar to real measured objects without any acquisition errors. Afterwards, volume of the grains using our proposed method and methods commonly used based on substitute diameters were computed. Obtained results, evaluated from two groups of grains (samples L0 and L10) are presented and compared in table 2.

TABLE 2

Average coal grain volume values evaluated from two groups of grains

Group	Volume evaluated as:				
	3D analysis	Projection diameter	Arithmetic diameter	Geometric diameter	Harmonic diameter
	V [mm^3]	V [mm^3]	V [mm^3]	V [mm^3]	V [mm^3]
L0	1.91	3.82	3.66	3.45	3.29
L10	2.04	5.17	4.73	4.49	4.30

6. Summary

Presented research describes the method of grain imaging and processing in 3D space. Raw data obtained from an optical profilometer was projected into 3D space, processed in the exact way and filtered. The crucial step in the data processing was reconstruction of the grains bottom data, which was not available for the measuring device head. The reconstructed grains were evaluated for their exact parameters. Obtained values were then compared with real volume values and also values obtained from methods commonly used, based on substitute diameters. Additionally, the presented algorithm was applied to measure the volume of the coal grains. The results presented show, that the 3D imaging methods applied to evaluate the volume of grains work well and give results better than the methods widely used. The additional advantage of this method is the fact, that image reconstructed in a computer memory can be processed and analyzed in many other ways to, for instance, to evaluate an objects surface area, shape factor and others. Moreover, the method described is not only dedicated to data gained from an optical profilometer. Data can be registered using any other measuring device which can obtain information about the height of a processed object.

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