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THE ABSTRACT OF DOCTORAL DISSERTATION

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THE OBJECTS MAPPING IN THREE-DIMENSIONAL SPACE WITH THE USE OF DIGITAL IMAGE PROCESSING AND ANALYSIS METHODS IN GEOLOGICAL AND MINING APPLICATIONS

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Introduction

The development of information technology has made computers being used in almost every area of life, regardless of whether it is research, engineering applications or entertainment. An example of such the area, which uses the latest achievements in information technology is a three-dimensional imaging. It is successfully applied in many scientific and technical subjects. It can also be used in issues related to mining and geology. Despite the fact, that recent years have brought more and more publications and research in this area, it can be stated that this subject is still little known and has been developed to a limited extent what can be found in many studies, where poorly automated or even manual methods of measurement are used. These methods are often characterized by low accuracy and time-consuming process of measurements. The fact that new technologies are not cheap and sometimes can cause many problems, has probably a considerable impact on this state of affairs. Nevertheless, evolution is inevitable, and the implementation of a growing number of new measurement methods is a matter of the near future.

Following this trend, a research to develop and apply innovative methods of acquisition, processing and image analysis in mining and geological applications has been undertaken. The study was conducted with the use of three-dimensional methods, which in combination with computers that provide more and more computing resources is natural direction of development of digital image processing and methods of analysis.

The research, which was carried out aimed at achieving an outlined subject matter, out of which, the following theses were verified:

1. Methods of image processing and analysis are useful for three-dimensional mapping of the rock walls surface, which may be important in the development of methods aimed at full automation of mining operations.
2. The methods, which are currently used to define geometric parameters of particle based on the analysis of substitute diameters are sometimes inaccurate and insufficient. They may be replaced by modern computer analysis and image processing methods, which enable complete mapping of grains and provide measurements of their geometrical parameters.

3. The positive results achieved by the automatic three-dimensional mapping of rock materials and objects, and analysis of their geometrical parameters will contribute to the development of three-dimensional mathematical morphology and image analysis methods. They also expand the scope of their application in issues related to mining and geology.

Description of research

The research, described in this thesis, has been divided into three main practical parts.

The first part focuses on topics related to imaging and determining geometrical parameters of grains. For the purpose of imaging three measuring devices were used: X-ray CT scanner, optical profilometer and confocal microscope. X-ray CT scanner enables full three-dimensional imaging of the structure of the studied grains, while the optical profilometer and a confocal microscope allowed to acquire data, describing only certain parts of tested objects - these devices allow measurement, only visible from the top, part of the grain. In order to be able to create complete three-dimensional representation of the examined grains and to determine their geometric parameters, the research has been undertaken in order to reconstruct the missing part of each grain. The proposed algorithm that performed this task was based on the assumption that the lower part, which requires reconstruction, is in some scale similar to the upper part of the grain. Moreover, it is based on image processing and analysis methods, and particularly important operations were performed in three dimensional space, which consisted mainly of morphological transformations. Based on the proposed method, missing information describing the shape of the particles was successfully reconstructed. That was confirmed by a series of tests verifying the correctness of reconstruction and reproducibility of the obtained results.

The next step was to prove the assumption that in case of performing some research on mapping grains in three-dimensional space and determining their geometric parameters X-ray CT scanner, optical profilometer or confocal microscope can be used interchangeably. This assumption was important due to the fact that X-ray CT scanner,

although it enables the full three-dimensional mapping of structure of the examined objects, is still poorly available and costly. Both, optical profilometers and confocal microscopes are more widely available and relatively cheaper.

The comparative studies were carried out on sets of particles of coal, for which average values of volume and dimensions were there determined and compared, assuming that the results obtained based on data from X-ray CT scanner were as close as possible to reality and they were treated as reference values. Average results, which were obtained are presented in table 1.

Table 1. Mean values of parameters calculated from data obtained using three different measuring devices.

	X-ray CT scanner	Confocal microscope	Optical profilometer
Length [mm]	1.741	1.805	1.804
Width [mm]	1.107	1.295	1.338
Height [mm]	0.790	0.716	0.711
Volume [mm^3]	0.508	0.509	0.533

In all cases, the heights of particles are the lowest in comparison with the widths and lengths. The values of length and width are also very similar for all devices - length is the largest of the dimensions. In case of the resulting volume values, the volume obtained based on data from confocal microscope is the closet to reference value and deviates by about 0.2%. The volume obtained on the basis of data from the optical profilometer deviates from the reference value by about 5%. However, either one or the other outcome seems to be at the acceptable level of correctness.

Therefore, taking the results of both size and volume into account, and the overall shape of the particles after reconstruction, it can be concluded that using proposed reconstruction algorithm, all three described devices can be used interchangeably.

Later in the study, based on positive results obtained, a research has been undertaken to verify whether the three-dimensional method produces results, which are similar to the commonly used manual methods based on so-called substitute diameters, which assume that analyzed particles have a spherical shape. The results obtained showed that the common manual methods produce results, which differ from real values, and in extreme cases, the differences reached tens of percents.

In the final stage of this part of the study, shape factors for a set of coal particles were calculated with the use of three-dimensional processing and image analysis methods. The results were then compared with parallel factors calculated in the two-dimensional space. One of the most interesting results was the one that showed that the same factors determined in two and three-dimensional space, along with the same variation of grain class size, show different trends in some cases. This fact, once again confirms that research on two-dimensional data, which do not represent three-dimensional objects fully, are often inaccurate and, in some cases, results obtained in this way may differ from reality.

In the second part of the study research was undertaken and involved application of three-dimensional image processing and analysis methods in order to perform mapping of rock walls. Such mapping was performed with the use of three different measuring devices. The first device was emitting laser lines, which along with applied methodology enabled the acquisition of data that described the shape of the surface of measured rock wall. A computer projector, which projects images of bit planes was the second device, which with similar measurement methodology to the laser line, enables the acquiring data, which describes the surface of the rock wall. The third device that was used was projector, which like the computer projector, was projecting images of bit planes.

During the measurements the correctness of mapping of the surface, which was measured has been verified. In addition, in order to check if these methods give expected result, tests were conducted and involved checking the volume of rock material, which was removed between the series of measurements. The research was conducted in two stages, i.e. in the first stage laser lines and computer projector were used, whereas the second one involved using bit planes projector. Table 2 presents the obtained results.

Table 2. The volume values with calculated deviations rates.

Real measurement Volume [dm^3]	Measurement type	Volume [dm^3]	Deviation [%]
0,79	Laser lines measurement	0,68	13,92
	Bit planes measurement	0,67	15,19
6,54	Two sides bit planes measurement	5,98	8,56

Positive results obtained were regarded as the basis for the measurement of the front of tunnel in the coal mine, which was successfully carried out. The result is significant in the context of automation of mining. Both underground mines and quarries, require knowledge of the topography of the excavation, in particular, the shape of the wall, where mining is carried out. This is crucial in a situation where the aim is to minimize, and ultimately to exclude human presence in the mining process. Positive results of described studies show that it is possible to develop automated methods for digital mapping of surface of excavation wall.

The next stage of research was to measure the rock material on the conveyor belt with the use of a parallel measurement methodology. During the measurements, with the use of digital image processing and analysis the amount of carried material has been measured and then compared with the actual quantity. An important step of this research was mapping the material in three-dimensional space, which allowed the appropriate transformation and analysis.

The third part of the research was in some measure the result of research on the first two topics. Due to the fact that during the research large amount of data was processed in three-dimensional space, ongoing work was very time-consuming. To shorten the processing, a decision to carry out changes in the source code of used algorithms was made, with the intention to make them more efficient and in the maximum possible way would utilize computing resources of the computer where the data algorithms were performed. The aim was achieved through parallelization of serial code in order to utilize all available processor cores during calculations.

After the implementation work on a specific image processing algorithm was done, a series of performance tests for the eight data sets were conducted. Performance tests were made in three different environments. In all of them JRE (Java Runtime Environment) in 64 bit version was installed. First of the test environments was a PC computer with the Intel Core i7 2.70 GHz 64-bit processor in mobile version with 16GB of RAM with Windows 7 64 bit operating system installed. The second device was PC desktop computer with the Intel Core i7 3.40 GHz 64-bit processor with 16GB of RAM with Windows 7 64 bit operating system installed. The third device was the server environment containing the Intel Xeon 3.30 GHz 64-bit processor with 16GB of RAM with CentOS 6.4 64-bit operating system installed.

During the tests positive speedups of parallel code were registered, and the results for the eight processes in most cases were the best. Figure 1 shows the speedup values obtained for the entire program, which included parallelized algorithm and some serial code.

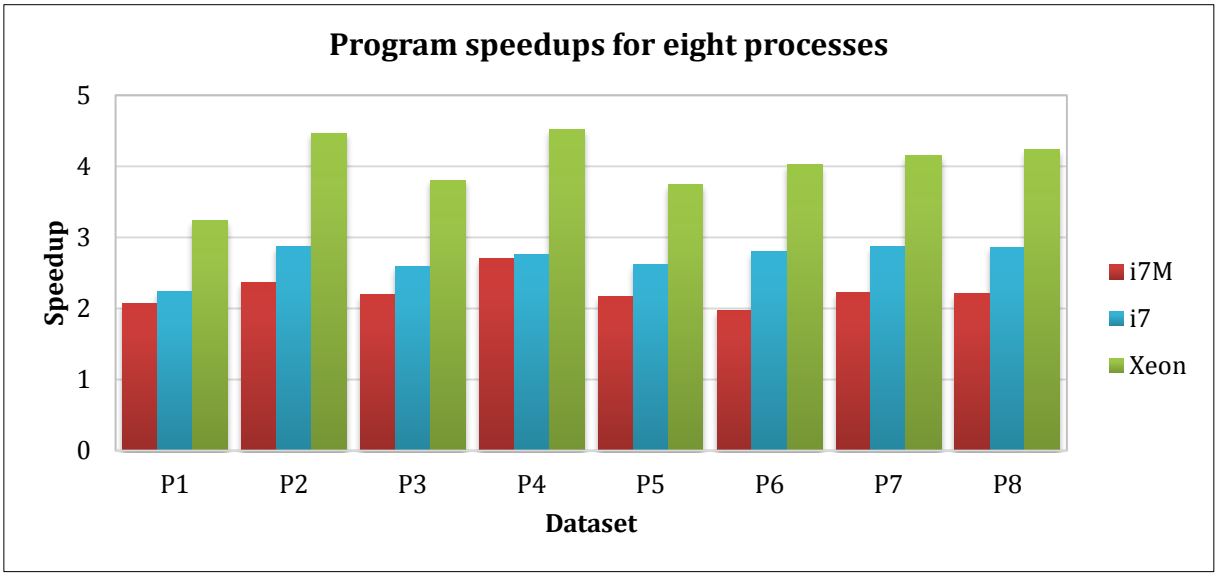

Figure 1. Program speedups values for each dataset with specified processors types.

Summary

Carried out research work leads to the following conclusions:

- With the use of modern, three-dimensional imaging techniques, applying image processing and analysis methods succeeded to perform work aimed at the digital mapping of grains and determination of their geometrical parameters. It is important that the results were calculated automatically and are at higher level of accuracy than the results obtained using manual methods. It has been confirmed by a number of tests that proposed method of grains reconstruction and reproducibility of the results are correct.
- Using three-dimensional data, which are fully describing the actual shape of the tested object, better results can be achieved than in case of using the method based on two-dimensional data. In extreme cases, it may occur that such methods can possibly generate results of a completely opposite characteristics.

- It was possible to develop successful low-cost methods for three-dimensional mapping of the surface rock walls, also using the equipment of own design, which was used in conditions of active underground coal mine. It should be emphasized that the use of methods produced good results of mapping rock walls, and created methodology can be further developed. Importantly, digitally mapped surfaces can be processed further, in any way, using algorithms, which are based on three-dimensional data.
- Although, computers, which are currently available on the market offer large computing resources, the resources are not fully utilized with programs with implemented serial code algorithms. Work, which was carried out on code parallelization, helped to improve the performance of three-dimensional space image processing algorithms, and thus save processing time by several times. The fact is that the parallelization itself turned out to be crucial, but also the environment in, which calculations are performed is significant.