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# Machine vision monitoring and particle size feed analysis

*This paper presents selected problems related to the use of machine vision techniques for the analysis of particle size distribution. The basic steps and conditions for acquiring granular material images are described, followed by further processing and analysis methods. The advantages of 3-D image acquisition and processing have been compared to 2-D image analysis. Several possible areas of application related to the supervision of material transportation, optimization of mineral processing systems, and bulk density measurements have also been presented.*

Key words: *particle size measurement, image analysis, coal preparation*

## 1. INTRODUCTION

Vision is one of the most important senses, providing most of the information processed by the human mind. The efficiency of the visual assessment of the surrounding world leads to search for methods of algorithmical processing of visual information using modern computer technology. For many years, there have been made multiple attempts to use visual information in the area of mineral processing. The first applications of image processing for particle size analysis were used to evaluate rock fragmentation (e.g., in quarries) after blasting, as it was the most efficient method for analyzing the size of large rock blocks in cases when sieve analysis was not applicable. The first studies were based on an analysis of the scanned images obtained by the photochemical method. The results of blasting were evaluated in natural illumination on the basis of static images [1–4]. The development of modern video methods is closely linked to advances in optoelectronic technologies, reduced costs and increased performance of digital still and video cameras, and increased computing power necessary for the analysis of complex systems (i.e., involving a very large number of particles, especially in a high-resolution images). In addition to the particle size analysis of rocks in quarries and opencast mining, the analysis of particle size distribution in boxes of rail carriages or trucks [4, 5] as well as an analysis of microscopic images of the smallest particles in the aqueous environment [6] and fly ashes [7] can be considered as a potential area for video monitoring applications. In this paper, particular attention has been paid to the problem of monitoring the flow of particle stream movement on a conveyor belt [8].

## 2. TWO-DIMENSIONAL IMAGE ACQUISITION

Image acquisition (i.e., its registration by an appropriate optical and optoelectronic system as well as its conversion to the digital form) is the first element of the whole multi-step image processing chain, determining the efficiency of its further analysis [8, 9]. The basic stages of the of image acquisition process from the real-world scene to the final digital form are shown schematically in Figure 1.

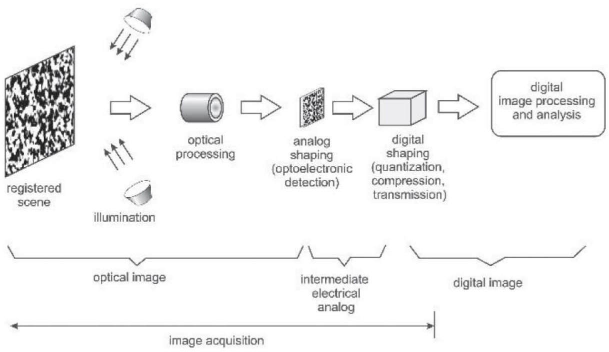


*Fig. 1. Basic stages of image acquisition chain*

In the case of coal particle size analysis, this task is particularly complex, as it is the most difficult type of rock to analyze due to its black surface color and the very low value of its surface reflection coefficient.

An additional impediment is the carbon shine, which changes the direction of light reflection and makes it difficult to analyze the shape and size of the grain. The situation is even more difficult in the case of wet coal; for example, due to the spraying of water associated with dust control. The black color of the rubber conveyor belt (especially when wet) makes it difficult to separate the analyzed objects (i.e., coal particles) from the background. Due to the above-mentioned factors, the ratio of the useful signal (brightness changes related to the size and shape of the particle surface) to the noise signal related to specular reflections and non-homogeneous illumination for the coal particle stream is much lower than for other mineral raw materials. Therefore, the machine vision size analysis systems used in rock mining and metal ore processing have not found wider use in coal mining applications. They require the development of specialized algorithms that take into account the special conditions described above and provide the adequate quality of the input image necessary for further analysis. As the image (analog or digital) is always the result of light reflected from the surface of the observed particle surface, special attention should be paid to providing adequate illumination. The light reflection from the particle surface is described by Lambert's law, and the shaded inter-particle spaces are the primary means for separating the touching particles. The best results can therefore be achieved with mixed illumination with a dominant contribution of side illumination, as it does not over-illuminate the inter-particle space [10].

Since only the surface layer of granular material is available for video analysis, there is the problem of evaluating the representativeness of this layer for the whole stream volume. Monte Carlo simulation studies [8] have shown that an important condition of this representativeness is to provide a relatively small layer thickness (i.e., comparable to the heightof the largest grains) and to measure at the beginning of the belt, where the influence of vibrational segregation (the mechanically induced falling of the finest particles into the free spaces between the larger grains) is still negligibly small.

## 3. THREE-DIMENSIONAL IMAGE ACQUISITION

The real surface of the granular material stream is a three-dimensional surface; hence, the common disadvantage of two-dimensional image (grayscale or color) analysis methods is the loss of direct depth information related to the third dimension (perpendicular to the two dimensions of the image plane) of both the individual particles as well as their entire population. Much more information can be obtained using the direct acquisition and analysis of three-dimensional images.

On the basis of the research carried out, it is possible to distinguish as particularly efficient (because of the use of the rectilinear motion of the conveyor belt) the following 3-D image acquisition methods [8, 11, 12]:

– stereovision [13, 14],
– laser triangulation,
– Time-of-Flight measurement.

Figures 2 and 3 compare the two-dimensional grayscale image and the corresponding height map; i.e., the three-dimensional image obtained by the Time-of-Flight measurement method. In this way, the three-dimensional images resulting from 3-D acquisition are characterized by a lower sensitivity to light irregularities and light reflections from the grain surface and, above all, make direct measurement of the height of both particular grains and the entire surface of the material stream possible.

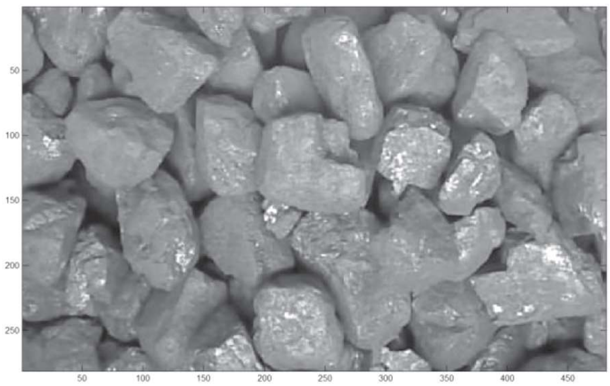


*Fig. 2. Example area of coal stream surface*

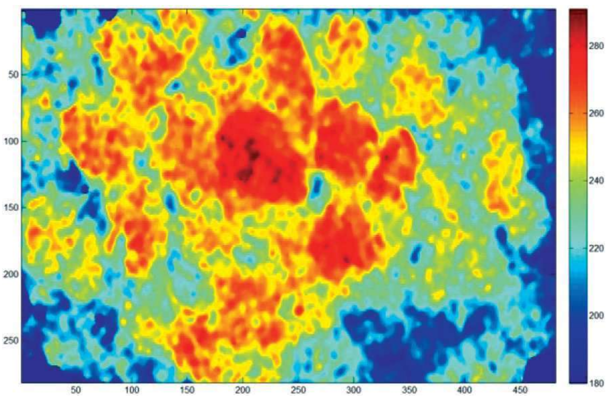


*Fig. 3. Height map; i.e., three-dimensional image corresponding to surface of Figure 2*

This allows for a more accurate estimation of the volume and mass of individual particles and makes it possible to determine the bulk density of the material (useful in many applications). It should be emphasized that the processing methods of three-dimensional and two-dimensional images are very similar in many aspects because the deepest (i.e., smallest height) inter-particle spaces defining the contours of the individual particles are at the same time the darkest areas (i.e., they have the lowest level of brightness) because of the high particle surface slope and shading associated with impeded illumination input.

## 4. IMAGE PROCESSING AND ANALYSIS

After image acquisition (i.e., digital recording), it is often necessary to apply a preprocessing stage in order to eliminate the interference caused by irregular illumination and local specular reflections from the shining fragments of the particle surface. The analyses [6] show that, in the case of uneven illumination, the best results can be obtained by intensity normalization based on the reference light pattern recorded on an empty belt. In order to eliminate specular reflection, image smoothing must be done in an adaptive manner so as not to blur the particle contours, making it difficult to precisely position and measure them. One method may be nonlinear diffusion, which locally smooths individual image areas to a varying degree depending on their local brightness or height gradient magnitudes [15].

After defining the particle contour [8, 9], it is necessary to determine the particle size in a manner corresponding to its behavior during sieve analysis, because sieving is accepted as a reference method for widespread industrial use. Since grain behavior during the screening process is determined by the two smallest of three orthogonal dimensions, one-parameter approximation methods (such as the diameter of the equivalent circle or the side of a square with an equivalent surface area of the grain contour) are too simplistic. The solution of this problem can be obtained by the elliptic approximation method, which allows us to describe the shape of the particle contour by means of an inertia equivalent ellipse. Grain behavior in the sieving process is determined by the shorter axis of the ellipse. An example of an elliptical approximation of a particle contour is shown in Figure 4.

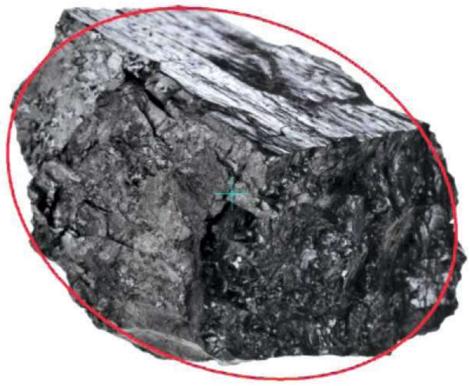

*Fig. 4. Elliptical approximation of coal particle contour*

For very fine particles, precise segmentation (which is necessary to individually describe and classify the individual particles) is a difficult and time-consuming task. Hence, it is convenient to use an alternative method in these cases that treats the entire area (or selected fragment of the area) of the granular material stream as a texture with size-specific statistical parameters. As a size-describing function of a granular material image, a spatial autocorrelation function can be assumed, as its local maxima simply correspond to the particle size most commonly encountered in the image [16]. This real autocorrelation function of a non-homogenous material can be expressed as a weighted sum of several basis functions determined for homogeneous samples corresponding to the reference particle size classes. The weight coefficients correspond to the proportion of individual grain classes in the total material stream. It is particularly important to select the algorithm for determining these weighting factors in a way that ensures the best possible representation of the empirically determined spatial autocorrelation function of the image (in the sense of the least squares method) and at the same time guarantees the physical meaning (i.e., limiting the range of coefficients to non-negative values). A good solution in this case may be the use of the NNLS (Non-Negative Least Squares) method [17].

## 5. POSSIBILITIES OF PRACTICAL APPLICATION

One of the simplest and (at the same time) very important practical ways to use the machine vision monitoring of particle size distribution may be the detection of large (oversized) large grains (rock blocks) that may cause disturbances in the transportation process by jamming or damaging the reloading devices or other equipment [18]. Another area of the application of video monitoring can be the direct tuning of the mineral processing crucial parameters (e.g., separation densities). The case of gravitational enrichment in pulsation jigs can be particularly important, as these devices are the most sensitive to changes in particle size distribution. For different size classes, the shape of the separation curve changes – the finer grains are separated less precisely than the coarser grains. Due to the fact that the feed passage time through the whole jig bed is relatively long, an on-line machine vision analysis of the feed particle size distribution at the jig inlet (Fig. 5) makes a much faster correction of the separation density value possible (especially in technological layouts with multiple jigs or multiple passage separation) than in a system equipped only with a radiometric ash monitor at the jig output.

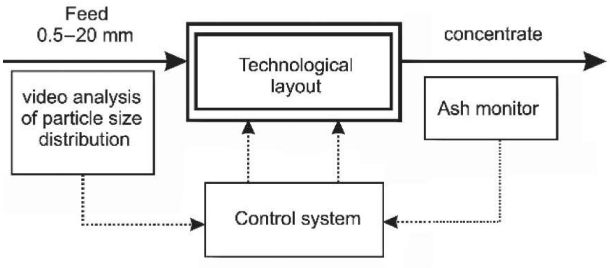


*Fig. 5. Application of on-line machine-vision analysis of particle size distribution for continuous operation tuning of jig plant [8]*

The calculations carried out in [8] show that, with high and frequent variability variation in the particle size distribution, application of the machine vision system can lead to a significant increase in the production value (achieved by the faster optimization of the separation densities in particular jigs). This can ensure a relatively quick cost reimbursement (in the order of several months or even weeks). In the case of 3-D image acquisition and processing, it is possible to extend monitoring system functionality by continuous measurement of the material stream bulk density (if the video monitoring system is connected to the conveyor belt scales [19]) and to control the uniformity of the material distribution on the conveyor belt. An example proposal of such a system is shown in Figure 6.

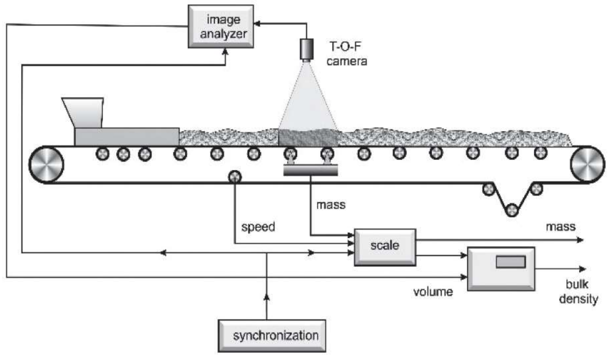


*Fig. 6. Example of dynamic bulk density measurement of granular material stream*

## 6. CONCLUSIONS

Advances in the field of optoelectronic technology make the development of video monitoring systems for grain size composition and the volume flow of raw material streams possible. Such systems can be used for the tuning of gravitational enrichment processes as well as for the video monitoring of belt conveyor system operation. The correct acquisition of two-dimensional images requires the proper illumination. Much more information can be obtained by using 3-D image acquisition and processing methods. Three-dimensional images contain direct information on the height of both the particular grains as well as the entire surface of the material stream.

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