System GRANICS for Particle-Size Distribution Determination by Photoanalysis

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Abstract

The system for determining the grain-size distribution of bulk material particles is described by the example of estimating the dimensions of crushed pieces of iron ore. The stages of the algorithm for processing of iron-ore particle images are illustrated. The results of full-scale testing of the system at the mining and processing plant are analyzed.

1 Introduction

Grain-size analysis of particles of bulk material is one of the most important indicators of the quality of many technological processes. Regarding to the process of ore crushing at mining enterprises, it allows operator to control the operation modes of large, medium and fine crushers depending on the obtained material distribution by grain-size classes. Thus, the optimization of a technological process for crushing solid material and the reduction of the company's costs for electricity and consumables are possible.

To estimate the grain-size of crushed ore pieces, it is necessary to construct the devices with advanced accuracy, reliability and speed as well as multifunctional properties. The devices based on vision systems are mostly met all these requirements. An important advantage of such systems is the non-contact method of measuring the parameters of the object of interest. This circumstance provides such devices with reliability and durability.

2 Materials and methods

The urgency of the problem of estimating the grain-size distribution of bulk materials particles is confirmed by the number of publications devoted to its solution [1-9]. This work presents the results of algorithmic and design-technological studies on the development of the hardware-software complex GRANICS. The complex is designed to determine the dimensions of bulk materials particles, in particular, pieces of medium-sized iron ore, moving on a conveyor or in bolting mill. The complex includes video sensors and a PC-station with a specific software which calculates the sizes of crushed pieces and performs their statistical processing. The principle of the GRANICS system operation is shown in Fig. 1.

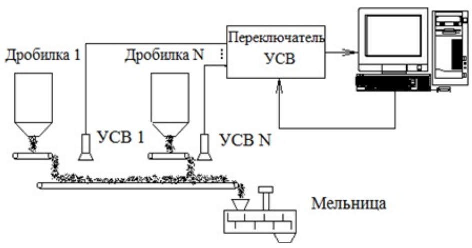

Figure 1. Scheme of the non-contact measurement of bulk material

Using the video capturing sensor (VCS), the original image of the crushed ore particles lying on the conveyor belt is captured (Fig. 2).

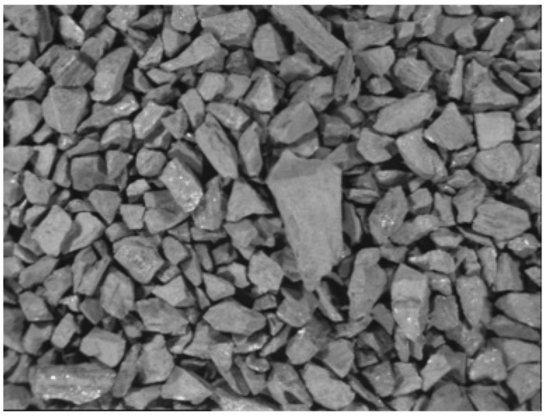

Figure 2. The initial image of crushed ore particles on the conveyor belt before processing

The algorithm for determining the dimensions of bulk particles is as follows. At the first stage, the original image $F(i,j)$ is processed by a median filter. The aperture of the median filter $W(i,j)$ is a square matrix of size 3x3. Traditionally, the filter response is calculated as:

$$MED[W(i,j)] = MED[\{f(i+k,j+l)\};k,l=\overline{-1,1}] \quad (1)$$

The nature of the impulse distortions on the resulting video images is in the form of "pepper" with an area of not more than 3 pixels. Given this fact, a sliding hybrid median filtering is used, which is as follows.

$$W(i,j) = \{clm(i,j-1), clm(i,j), clm(i,j+1)\}, \quad (2)$$

where $clm(i,j) = \{f(i+k,j), k=\overline{-1,1}\}$

Then the response of the sliding hybrid median filter will be calculated according to the formula

$$HMED[W(i,j)] = MED[MED[clm(i,j-1)], MED[clm(i,j)], MED[clm(i,j+1)]] \quad (3)$$

When shifting $W(i,j)$ by one position, we get

$$HMED[W(i,j+1)] = MED[MED[clm(i,j)], MED[clm(i,j+1)], MED[clm(i,j+2)]] \quad (4)$$

It can be seen from (1) and (2) that with $W(i,j)$ of 3x3 size, the number of sorting operations is clearly reduced by 2 times. The resulting image is subjected to smoothing filtering using a 17x17 square mask consisting of unit elements. The next stage is borders emphasizing which can be implemented by a nonlinear method of detecting the differences, based on the homomorphic image processing proposed by Wallis [10]. According to this method, the element of the contrasted image is defined as

$$G(j,k) = \frac{1}{4}\log\left\{\frac{[F(j,k)]^4}{F(j-1,k)F(j+1,k)F(j,k-1)F(j,k+1)}\right\} \quad (5)$$

As a result of these transformations, a contour image of the visible layer of crushed ore pieces $F^c(i,j)$ is obtained (Figure 3), which is the aggregate of M disjoint regions

$$F^c(i,j) = \bigcup_{k=1}^{M} S_k \ . \tag{6}$$

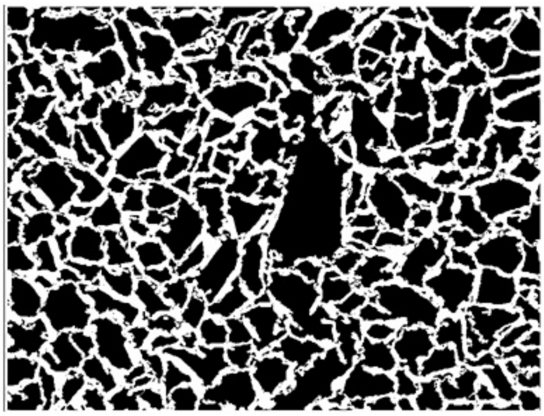

Figure 3. Contour image of crushed ore particles

It is noted in [9] that one of the main features that allow us to classify an isolated region S_k as a particle of crushed ore is a sign of roundness calculated by formula

$$R_k = \frac{\sum_{i=1}^{L} (d_i^k - avg(d_i^k))^2}{L} \tag{7}$$

where $d_i^k = \sqrt{(x_i^k - C_x^k)^2 + (y_i^k - C_y^k)^2}$ is a distance from each boundary point $(x_i^k, y_i^k), i = \overline{1, L}$ of the region S_k to its center $(C_x^k, C_y^k) = (mean(x_m^k), mean(y_m^k)), \{x_m^k, y_m^k\} \in S_k$,

and $avg(d_i^k) = \frac{\sum_{i=1}^{L} d_i^k}{L}$

The segmentation procedure is implemented as follows. For each $S_k, k = \overline{1, M}$ R_k is calculated. If R_k <THRESHOLD, it is classified as an image of crushed ore particles. If R_k > = THRESHOLD, then the selected fragment of the image is subdivided into the subdomains by the "watershed" algorithm [11,12]. In Fig. 4 the results of this algorithm is shown.

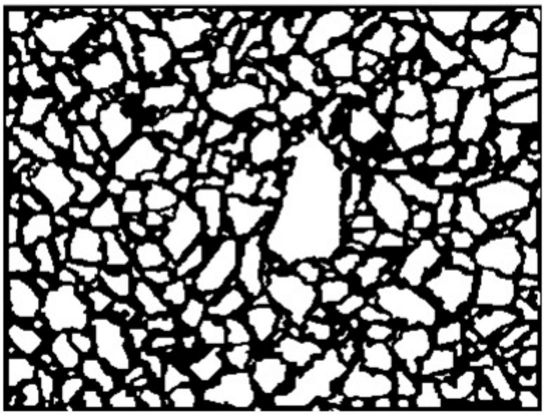

Figure 4. Formation of ore particle images using the "watershed" algorithm

At the next stage, for each selected area, its main axis is calculated, the length of which E_{2a} is determined by the formula

$$E_{2a} = \sqrt{\frac{p^2}{2\pi^2} + \frac{2\pi}{A}} + \sqrt{\frac{p^2}{2\pi^2} - \frac{2\pi}{A}} \tag{8}$$

where p is the perimeter of the selected area, and A is its area in pixels. In Fig. 5 main axes are represented by black lines. In the crosswise direction the maximum width E_{2b} of the ore particle region is determined, the value of which is calculated in this way

$$E_{2b} = \sqrt{\frac{p^2}{2\pi^2} + \frac{2\pi}{A}} - \sqrt{\frac{p^2}{2\pi^2} - \frac{2\pi}{A}} \tag{9}$$

In Fig. 5 lines corresponding to the maximum width of the ore particle region are drawn in white. These axes will characterize the dimensions of bulk material pieces.

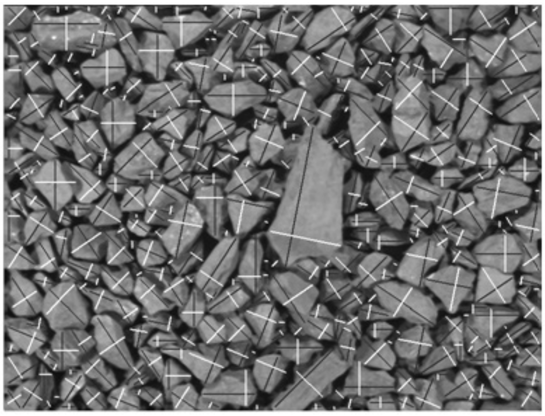

Figure 5. The results of estimating the dimensions of crushed ore pieces

3 Testing and Results

Industrial tests of the GRANICS complex were carried out, in particular, at the Erdenet Mining Corporation, Mongolia. According to the program of industrial tests, the central research laboratory of the plant (CRL) sampled the ore after fine crushing from the conveyor No. 18 in order to determine the condition and nominal grain-size, with parallel fixation of the same parameters of the crushed ore according to the GRANICS output. The grain-size distribution of the ore is shown in Tables 1 and 2.

Table 1. Grain-size distribution according to CRL analysis

Grain-size class, mm	Exp №1	Exp №2	Exp №3	Exp №4	Exp №5	Exp №6	Exp №7
20	0.09	0.08	0.05	0.14	0.08	0.06	0.13
18	0.46	0.61	0.53	0.73	0.48	0.50	0.52
15	2.32	2.46	2.45	3.76	2.80	2.74	2.37
12.5	11.48	11.72	11.46	14.02	13.38	10.85	12.08
6.3	32.91	33.67	35.47	32.94	35.02	31.43	36.66
-6.3	52.74	51.46	50.04	48.41	48.24	54.42	48.24
TOTAL	100.00	100.00	100.00	100.00	100.00	100.00	100.00

Table 2. Grain-size distribution according to GRANICS output result

Grain-size class, mm	Exp №1	Exp №2	Exp №3	Exp №4	Exp №5	Exp №6	Exp №7
20	0.47	0.62	0.46	0.44	0.67	0.43	0.66
15	2.34	3.13	2.66	2.17	2.93	2.15	2.95
12	7.82	9.65	8.40	7.39	8.79	7.30	8.76
10	9.73	11.32	10.49	9.37	10.34	9.44	10.34
6	20.16	22.49	21.29	19.05	19.80	19.60	20.87
-6	59.48	52.79	56.70	61.58	57.47	61.08	56.42
TOTAL	100.00	100.00	100.00	100.00	100.00	100.00	100.00

To perform a comparative analysis of the obtained data, the results of determining the nominal grain-size of the crushed ore and the content of the "+15 mm" grain-size class are presented in Table 3.

Table 3. The nominal grain-size of crushed ore and the content of the grain-size class "+15 mm"

Experiment №	nominal grain-size, мм		content of grain-size class "+15 mm"	
	CRL	GRANICS	CRL	GRANICS
1	14.30	13.81	2.87	2.81
2	14.40	14.37	3.15	3.75
3	14.40	14.03	3.03	3.12
4	14.80	13.71	4.63	2.61
5	14.50	14.26	3.36	3.60
6	14.40	13.71	3.30	2.58
7	14.40	14.26	3.02	3.61
average value	14.46	14.02	3.34	3.15
relative error	3.01%		5.48%	

4 Conclusion

System GRANICS and CRL have different principles of evaluation of the same technological process. However, the above results show that the relative error of the GRANICS complex in determining of the nominal grain-size of the crushed ore was only 3.01% compared to the CRL, and in the evaluation of the controlled class "+ 15mm" the error is 5.48%.

Thus, the performed industrial tests illustrate that the complex accurately determines the grain-size distribution of the crushed particles.

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