Quality assessment of primary crushing using hardware-software appliance «GRANICS»

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Abstract. A system for determining the grain size composition of particles of bulk material is described using the example of measurement the geometry of prills of crushed iron ore. The hardware and algorithm peculiarities are given. The stages of the image processing algorithm for crushed particles detection and analyzing are illustrated. The results of full-scale testing of the system at the ore mining and processing enterprise are analyzed. The maximum absolute error of the designed hardware-software appliance is 4.2% and the average error is 3% for the “+150mm” class which is of most importance for the given task of primary crushing quality control.

1. Introduction

At the moment the operational size control in the spalling and tine crushing circuits is necessary for the optimal performance of the dressing department which assumes the output of the concentrate with consistent quality at planned productivity of the basic process equipment. The minimum time for the grain size analysis in a laboratory setting is 1.5 hours at least; this is why the productivity of the spalling and tine crushing circuits equipment cannot be adjusted on the fly.

The problem of the efficient grain size analysis of the crushed material is observed in a number of researches [1-11]. According to experts, up to 30% of the expenses involved in extraction and processing of the ore material are referred to the blasting operations. Simulation and quality analysis of these operations will lead to the significant cost cut of an ore mining and processing enterprise [9].

The on-line control of the geological composition of the ore material is a major asset for the ore processing. This problem could be solved by the extraction and analysis of the color and textural features of prills [1,4]. A number of systems for the operational grain size control of the crushed or pelletized material is designed and implemented by now. In [10] the brief review of such systems as SPLIT, WIPFRAG, FRAGSCAN, CIAS, IPACS, TUCIPS is given.

This paper gives the algorithmic and design-engineering details of the R&D project named hardware-software appliance «GRANICS» (Fig. 1) [14,15].
2. Materials and methods

The structural configuration of the 4-channel video-based control system is given in Fig. 2.

The system includes the following location-aggregated components (units):
1. Sensor 1, ..., Sensor 4 – video image readers with LED backlighting
2. Switchboard, including:
   - Receiver-corrector unit with master controller, 4 pcs.
- Power supplies for video image readers, 4 pcs.
- PC interface unit, 1 pc.

3. IBM PC with framegrabber card and operator console.

Video image readers are connected with correspond receiver-corrector units by two twisted pairs, feeding them on a separate three-core power low-voltage cable. A power scheme in which the power supplies are located in close proximity to the video image readers, and the power is fed via the power cable 220V is also possible.

The principle of the «GRANICS» operating is as follows. The initial image $F(i, j)$ of crushed ore prills lying on the belt conveyor is taken using video image readers (sensors). 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 matrix of 3x3 cells. Conventionally, the filter response is calculated as:

$$MED[W(i, j)] = MED[f(i + k, j + l); k, l = -1, 1].$$

(1)

The nature of the impulse noise on the resulting video images is "pepper" with an area of no more than 3 pixels. Taking this fact into account, a sliding hybrid median filtering is implemented. The aperture of the median filter is represented in the form:

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

(2)

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

Then the response of the sliding hybrid median filter $HMED[W(i, j)]$ will be calculated by the formula (3):

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

(3)

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

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

(4)

It can be seen from (3) and (4) that with $W(i, j)$ size of 3x3, the number of sorting operations is reduced by half. The output image is subjected to smoothing filtering using a 17x17 square mask consisting of single elements. The next step is boundary highlighting, which can be implemented by a non-linear method of the brightness difference detecting based on the homomorphic image processing [12]. According to this method, the element of the contrasted image $G(j, k)$ is defined as:

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

(5)

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

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

(6)

It is noted in [11] that one of the main feature to classify an isolated region $S_k$ as an image of a prill is a roundness which is calculated by formula:

$$R_k = \frac{\sum_{l=1}^{L} (d^k_l - \text{avg}(d^k_l))^2}{L} ,$$

(7)
where \( d^k_i = \sqrt{(x^k_i - C_x^k)^2 + (y^k_i - C_y^k)^2} \) is a distance from each boundary point \((x^k_i, y^k_i), i = 1, L\) of region \(S_k\) to its center \((C_x^k, C_y^k) = (\text{mean}(x^k_m), \text{mean}(y^k_m)), \{x^k_m, y^k_m\} \in S_k\).

The segmentation procedure is implemented as follows. For each \(S_k, k = 1, M\) \(R_k\) is calculated. If \(R_k < \text{THRESHOLD}\), it is classified as an image of a prill. If \(R_k \geq \text{THRESHOLD}\), then the selected fragment of the image is subdivided into the subdomains by the watershed algorithm \([13]\). In the next step, for each selected area, its main axis is calculated. In Fig. 3 main axes are represented by black lines. Sideways on to the main axes of the selected regions, the maximum width of the image region of the prill is determined. In Fig. 3 lines corresponding to the maximum width of the image region of the prill are drawn in white.

It is these dimensions that will characterize the geometry of the prills that correspond to the sieve analysis.

**Figure 3.** Results of the grain size analysis of crushed ore: a – prills, b – prills and moro

The main problem of such vision-based systems is the determination of the weight fractions of crushed material classes from the 2D image of the filling layer \([10]\). The following methods for determining the particle size are analyzed:

1. **Feret diameter:**

\[
D_F = \frac{P}{\pi},
\]

where \(P\) is the perimeter of the prill.

2. **Martin diameter** - a line dividing the particle into two equal halves. Depends on the orientation of the particle, but with a large number of particles and the same measurement technique, satisfactory results are obtained.

3. **Average particle diameter:**

\[
D_{cp} = \sqrt{\frac{D_{\text{min}} D_{\text{max}}}{2}},
\]

where \(D_{\text{min}}\) is the diameter of the maximum inscribed circle, and \(D_{\text{max}}\) is the diameter of the minimal circumscribed circle.

4. The diameter of the equivalent circle:
where $S$ is the area of a particle.

The best convergence with sieve analysis was demonstrated by the equivalent circle method.

3. Testing and conclusion

Industrial tests of the «GRANICS» were carried out, in particular, at EVRAZ-KGOK ore mining and processing enterprise. According to the program of industrial tests, the laboratory took samples of primary crushing output from conveyor No. 2 in order to determine the output of the size classes: -50mm, 50mm, 70mm, 100mm, 150mm with parallel reporting of the same parameters from «GRANICS». The grain-size composition of the crushed material passed into the spalling and tine-crushing circuits is presented in Table 1.

Table 1. Testing results from section № 2 of primary crushing complex at EVRAZ-KGOK

| Expr № | Data source | Sample mass, kg | Class size output, % |
|--------|-------------|----------------|---------------------|
|        |             | +150 | +100 | +70 | +50 | -50 |
| 1      | Laboratory | 23.1 | 25.5 | 9.1 | 4.0 | 38.3 |
|        | PAC «GRANICS» | 21.0 | 19.0 | 15.0 | 8.0 | 37.0 |
|        | Absolute error | 2.1 | 6.5 | 5.9 | 4.0 | 1.3 |
| 2      | Laboratory | 14.1 | 11.8 | 11.2 | 5.1 | 57.8 |
|        | PAC «GRANICS» | 12.0 | 19.0 | 16.0 | 8.0 | 45.0 |
|        | Absolute error | 2.1 | 7.2 | 4.8 | 2.9 | 12.8 |
| 3      | Laboratory | 7.1 | 10.1 | 13.4 | 4.5 | 64.9 |
|        | PAC «GRANICS» | 11.0 | 13.0 | 16.0 | 7.0 | 53.0 |
|        | Absolute error | 3.9 | 2.9 | 2.6 | 2.5 | 11.9 |
| 4      | Laboratory | 20.2 | 11.6 | 4.4 | 10.2 | 53.6 |
|        | PAC «GRANICS» | 16.0 | 17.0 | 14.0 | 7.0 | 46.0 |
|        | Absolute error | 4.2 | 5.4 | 9.6 | 3.2 | 7.6 |
| 5      | Laboratory | 20.3 | 15.4 | 4.4 | 9.4 | 50.5 |
|        | PAC «GRANICS» | 23.0 | 23.0 | 8.0 | 6.0 | 40.0 |
|        | Absolute error | 2.7 | 7.6 | 3.6 | 3.4 | 10.5 |
|        | **Average error** | **3.0** | **5.9** | **5.3** | **3.2** | **8.8** |

The above-mentioned results show that the maximum absolute error of the «GRANICS» is 12.8% when determining the "-50mm" class. However, the most important indicator for assessment the quality of primary crushing is the content of the class "+ 150mm". The maximum error for this class is 4.2%, and the average error for the five experiments is no more than 3%.

«GRANICS» and the ore preparation laboratory have different principles of measurement the parameters of the same technological process. However, the obtained results show that the designed complex gives reasonable approximation of the grain size composition of the crushed material.

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