PAPER • **OPEN ACCESS**

The use of homomorphic image processing to analyze coke grading

To cite this article: V N Krouglov *et al* 2020 *IOP Conf. Ser.: Mater. Sci. Eng.* **966** 012135

IOP Conf. Series: Materials Science and Engineering **966** (2020) 012135 doi:10.1088/1757-899X/966/1/012135

The use of homomorphic image processing to analyze coke grading

V N Krouglov[1, 4], A G Gruh[2], A L Gapak[2] and I Khurelchuluun[3]

[1] Ural Federal University named after the First President of Russia B N Yeltsin, 19, Mira str., Yekaterinburg, 620000, Russia
[2] EVRAZ KGOK JSC, 2, Sverdlova str., Kachkanar, 624350, Russia
[3] Erdenet Mining Corporation SOE, Erdenet, 61027, Mongolia

E-mail: [4] v.krouglov@mail.ru

Abstract. The estimation of the geometrical sizes of particles of crushed solid fuel (coke), moving on the conveyor belt, is associated with a number of technical difficulties. One of the problems is the need for a non-invasive way of determining particle geometry. A promising way to solve it is to use devices based on machine vision systems. This paper describes the algorithmic part of the prototype of such a device. It is proposed to improve the quality of boundary detection between fragments of coke particles to perform homomorphic processing of the initial low-contrast video images. The algorithm for calculating the Fourier spectrum has been optimized based on the Fast Fourier Transform (FFT) with the mixed base. As a result, it becomes possible to reduce the computational cost for calculating two-dimensional Fourier spectra for complex multiplication operations by 1.33 times, and the number of complex addition operations by 1.67 times. The software of the prototype, built using the proposed methods, made it possible to obtain good convergence of the results for assessing the particle size distribution of samples of crushed coke with laboratory estimates. Thus, the maximum absolute average error of the machine vision system in assessing the size of crushed coke is only 3.37%, and the maximum error for all measurement classes do not exceed 6.9%.

1. Introduction

The sintering process of the sinter burden is largely determined by the quality of the preparation of solid fuels - finely divided coke particles. The grain size distribution of such particles is usually in the range from 0.1 mm to 5–7 mm., with more than 80% of them being in the range of 1–3 mm. Coke particles after crushing enter the charge preparation plant through a system of conveyors, where the sinter burden is prepared. It has to be mentioned that the conveyor speed is about 1 m/s. To analyze the grain size distribution of crushed coke particles under such conditions, the control system should fulfill the following requirements:

- high accuracy in estimating particles geometry,
- a short time to complete such estimates,
- high reliability of operation.

One of the most promising devices for solving such problems are devices based on vision systems [1-4]. A device developed under the state contract 3170ГС1/48564 with FASIE fund can serve as a prototype of such an instrument. The images of the filled layer formed by coke particles with various size distribution obtained using this prototype are given in Figure 1.

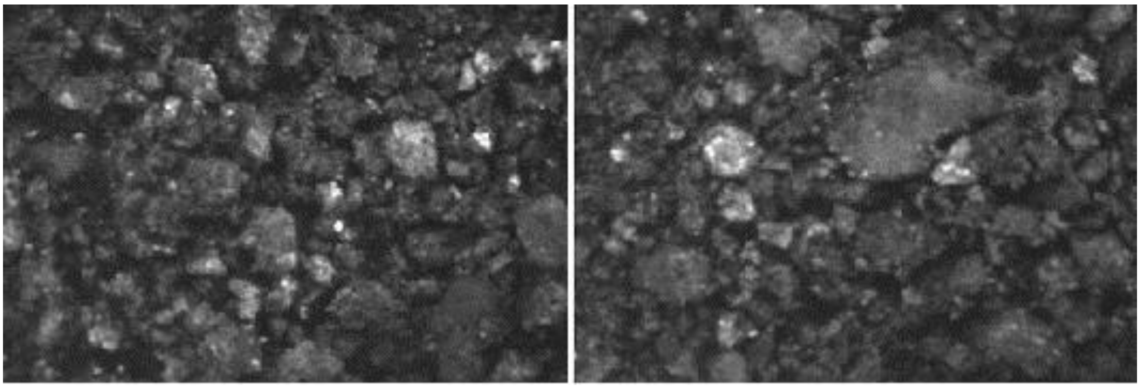

Figure 1. Images of crushed coke particles: desired (left) and enlarged (right) particle size distribution

The prototype was installed and tested on the conveyor No. 47 of the charge preparation plant of EVRAZ KGOK JSC.

To determine the geometry of visible coke particles, it is necessary to perform image segmentation, that is, to split the image into fragments corresponding to the particles. One approach to segmentation is to initially build the boundaries between images of coke particles. This study is devoted to the problem of identifying the boundaries of the regions of coke particles.

2. Methods

From literature [5, 6] it is known that the spectrum of the image obtained using a video camera is shifted to the low-frequency region. For a qualitative construction of the boundaries between image fragments, sharp changes in the brightness function $f(x,y)$, $x=\overline{0,L-1}$, $y=\overline{0,M-1}$ are necessary. In turn, the steepness of the brightness difference is determined by high-frequency harmonics in the image spectrum $F(\omega_x,\omega_y)$, $\omega_x=\overline{0,L-1}$, $\omega_y=\overline{0,M-1}$. In our opinion, it is most expedient to use homomorphic processing of the original image to enhance them. Such processing, in addition to increasing the image contrast, eliminates the uneven illumination of the observed surface. The theory of homomorphic processing is described in detail in [5]. As a center-symmetric transfer function, it is recommended to use any of the high-pass filters. The experiments conducted by the authors showed that the best results for adjusting images of wet coke particles are obtained using a modified high-frequency Gaussian filter, the transfer function of which is as follows:

$$H(\omega_x,\omega_y)=|sH-sL|\cdot\left(1-exp\left(-\frac{C*D^2(\omega_x,\omega_y)}{D_0^2}\right)\right)+sL, \quad (1)$$

where sH and sL are parameters correcting the high-frequency and low-frequency components of the spectrum $F(\omega_x,\omega_y)$; constant C determines the slope of the transfer function of the filter in the region between sH and sL; D_0 is the cutoff frequency of the filter, and the $D(\omega_x,\omega_y)$ parameter for the centrally symmetric spectrum is determined by the formula:

$$D(\omega_x,\omega_y)=\sqrt{(\omega_x-L/2)^2+(\omega_y-M/2)^2} \quad (2)$$

When implementing homomorphic filter, the highest computational complexity is associated with the translation of the image $f(x,y)$ presented in spatial coordinates into the frequency domain and vice versa. The Fourier spectrum [8] is most often used as the latter. The calculation of the direct $\Im^{+}\{f(\omega_x,\omega_y)\}$ and inverse $\Im^{-}\{f(\omega_x,\omega_y)\}$ discrete Fourier transforms (DFT) [5, 6, 7] is

IOP Conf. Series: Materials Science and Engineering **966** (2020) 012135 doi:10.1088/1757-899X/966/1/012135

implemented using fast Fourier transform (FFT) algorithms. FFT algorithms can be implemented in various ways, but the most common is the FFT algorithm at base 2. This means that the size of the input image in both coordinates must be equal to the power of two: $M = 2^m$ and $L = 2^l$. In our experiments, the BASLER aca1600-60 gm digital video camera with a resolution of 1600×1200 pixels was used to obtain video images. None of the dimensions of the image formed by such a camera is a power of two. In such situations, the input array is supplemented with zeros so that the length of each coordinate becomes equal to power of 2. In our case, this number is $N = 2048 = 2^{11}$. The complexity of the FFT algorithm in base 2 for calculating the two-dimensional Fourier spectrum with the dimension $N \times N$, at $N = 2048$, expressed as the number of complex operations of multiplication $\dot{M}u$ and addition $\dot{A}d$ without optimization of calculations, is:

$$\dot{M}u \approx \left((N/2) \cdot (\log_2 N - 1) \right) \cdot N \cdot 2 = 41943 \cdot 10^3 \text{ and}$$

$$\dot{A}d = \left(N \cdot (\log_2 N \right) \cdot N \cdot 2 = 92274 \cdot 10^3$$

If the calculation of the two-dimensional spectrum is optimized and the zero lines are not processed, the complexity of calculating the two-dimensional FFT decreases:

$$\dot{M}u \approx \left((N/2) \cdot (\log_2 N - 1) \right) \cdot 1200 + \left((N/2) \cdot (\log_2 N - 1) \right) \cdot N = 33259 \cdot 10^3 \text{ and}$$

$$\dot{A}d = \left(N \cdot (\log_2 N \right) \cdot 1200 + \left(N \cdot (\log_2 N \right) \cdot N = 73171 \cdot 10^3$$

To further reduce the computational complexity of calculating the Fourier spectrum, it is proposed to use the mixed base FFT algorithm instead of the FFT algorithm at base 2 [8]. To do this, we should reduce the width of the processed frame to $M = 1536$, and increase the height to $L = 1280$ pixels. In this case, the loss of initial information will be only $100 - (1563/1600) = 4\%$. Added lines are filled with zeros as previously. The scheme of the FFT algorithm for computing by lines is converted to the form $M = 1536 = 2^9 \cdot 3$, that is, initially 9 iterations were performed with a 2×2 DFT kernel, and the last iteration with a 3×3 DFT kernel. The complexity of computing the kernel of the DFT 3×3 is: $\dot{M}u = 4$ and $\dot{A}d = 6$. The number of operations for calculating the Fourier spectra for all 1,200 lines (zero lines are not processed) is:

$$\dot{M}u \approx \left((M/2) \cdot 9 + 4 \cdot 512 \right) \cdot 1200 = 10752 \cdot 10^3 \text{ and}$$

$$\dot{A}d = \left(M \cdot 9 + 6 \cdot 512 \right) \cdot 1200 = 20275 \cdot 10^3$$

The column length L is decomposed as $L = 1280 = 2^8 \cdot 5$, that is, 8 iterations are initially performed with a 2×2 DFT kernel, and the last iteration with a 5×5 DFT kernel. The complexity of computing the DFT 5×5 kernel is: $\dot{M}u = 16$ and $\dot{A}d = 20$. The number of operations for calculating the Fourier spectra for all 1536 columns is:

$$\dot{M}u \approx \left((L/2) \cdot 8 + 16 \cdot 256 \right) \cdot 1536 = 14156 \cdot 10^3 \text{ and}$$

$$\dot{A}d = \left(L \cdot 8 + 20 \cdot 256 \right) \cdot 1536 = 23593 \cdot 10^3$$

The total complexity of calculating the two-dimensional Fourier spectrum of 1536×1280 pixels with the FFT algorithms at a mixed base is:

$$\dot{M}u \approx 24908 \cdot 10^3 \text{ and } \dot{A}d = 43868 \cdot 10^3$$

The acceleration coefficient (AC) for complex operations of multiplication is $AC_{\dot{M}u} = 33259 \cdot 10^3 / 24908 \cdot 10^3 = 1.33$, and for complex operations of addition is $AC_{\dot{A}d} = 73171 \cdot 10^3 / 43868 \cdot 10^3 = 1.67$.

IOP Conf. Series: Materials Science and Engineering **966** (2020) 012135 doi:10.1088/1757-899X/966/1/012135

3. Results and Discussion

The algorithm of the homomorphic image processing implemented by the proposed technique turned out to be highly efficient from a computational point of view and allowed to significantly improve the contrast of the input image. Figure 2 shows the results of homomorphic filtering of the images shown in Figure 1, using a modified Gaussian high-pass filter.

The numerical values of the filter parameters were as follows: $sH = 2$, $sL = 1$, constant $C = 3$, filter cutoff frequency $D_0 = 32$. Figure 3 illustrates the final results of processing the images shown in Figure 1. Dark lines on the fragments of coke particles indicate their maximum sizes. In the perpendicular direction, the white lines indicate the sizes that correspond to the results of the screening of these particles.

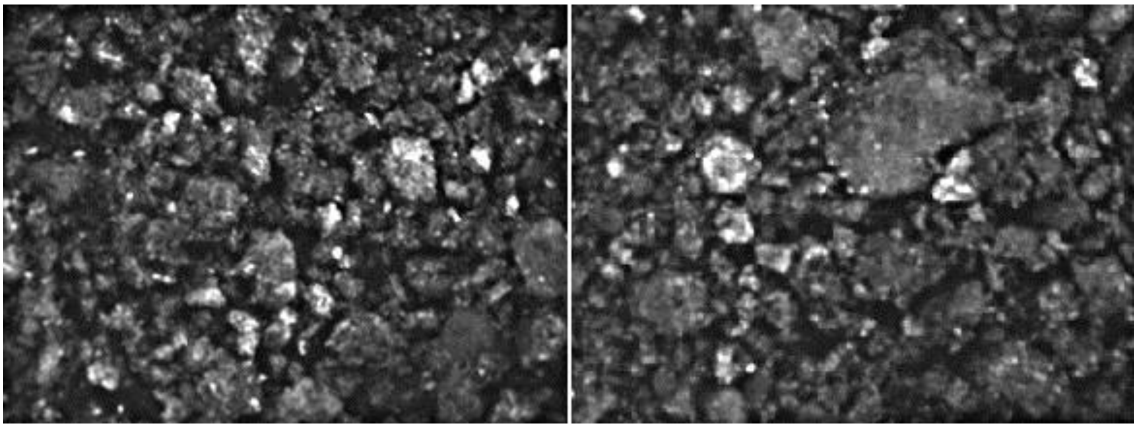

Figure 2. Results of homomorphic processing of images presented in Figure 1

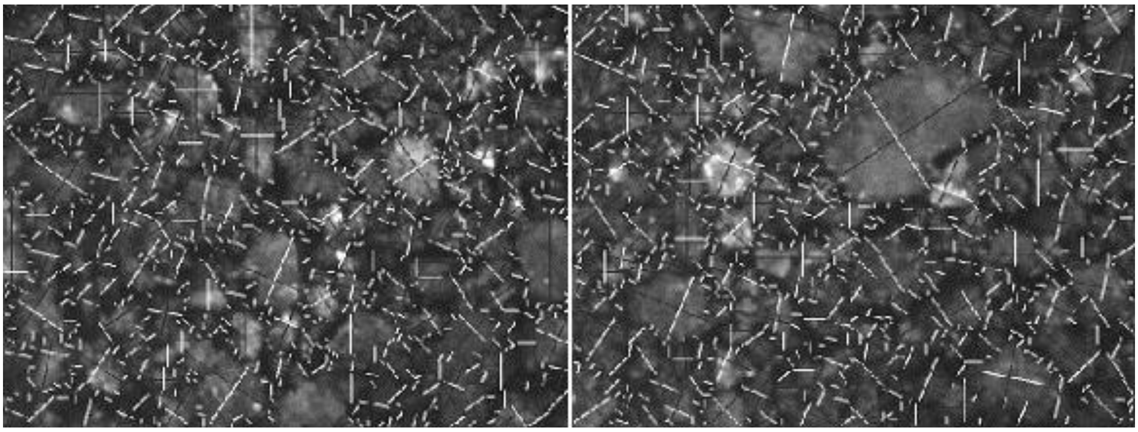

Figure 3. Results of the evaluation of the geometric dimensions of the coke particles shown in Figure 1

A number of experiments at EVRAZ KGOK JSC were conducted to evaluate the quality of the algorithm for evaluating the grain size distribution of solid fuel particles. The prototype of the developed device based on the machine vision system (MVS device) was installed on the conveyor No. 47 of the charge preparation plant of EVRAZ KGOK JSC. After the conveyor stopped, frames of the filling layer formed by coke particles were recorded and this material was sampled. Subsequently, the obtained samples were scattered in the laboratory of the plant on sieves, and the generated video images were processed using the methods proposed above. The results of these experiments are shown in Table 1.

Table 1. The results of the evaluation of the grain size distribution of solid fuel particles obtained in the laboratory of JSC EVRAZ KGOK and by MVS device.

Sample No.	Source	Grain size distribution, %						Mean error	Max error
		+5	+4	+1	+0.5	+0.1	-0.1		
1	Laboratory	0.8	1.0	46.5	15.4	10.5	25.8	2.37	5.5
	MVS device	0	0	46	17	16	21		
	Error	0.8	1	0.5	1.6	5.5	4.8		
2	Laboratory	1.1	1.7	46.3	15.6	14.3	21.0	1.80	4.3
	MVS device	0	2	42	18	16	22		
	Error	1.1	0.3	4.3	2.4	1.7	1		
3	Laboratory	1.5	1.6	45.6	14.9	12.4	24.0	1.70	3.0
	MVS device	0	2	45	17	15	21		
	Error	1.5	0.4	0.6	2.1	2.6	3.0		
4	Laboratory	20.6	4.8	34.5	14.3	18.7	7.1	3.37	6.9
	MVS device	17	3	37	15	14	14		
	Error	3.6	1.8	2.5	0.7	4.7	6.9		
5	Laboratory	17.7	4.3	37.5	14.5	18.4	7.6	3.07	6.4
	MVS device	19	2	40	14	12	13		
	Error	1.3	2.3	2.5	0.5	6.4	5.4		

Devices based on vision systems and laboratory installations for assessing the grain size distribution of crushed material have different principles for evaluating the same process. However, the presented results show a high convergence of the results obtained using the MVS device and the laboratory method with the correlation coefficient 0.974. In particular, the maximum mean error of the MVS device in assessing the size of crushed coke was only 3.37%, and the maximum error for all measurement classes did not exceed 6.9%.

4. Conclusion

The results of the studies showed the feasibility of using homomorphic processing of the original video images of crushed coke particles in order to increase their contrast. This allowed for better image segmentation and, as a result, increased the accuracy of estimating the geometric dimensions of coke particles. The optimization of computational costs in the calculation of two-dimensional Fourier spectra increased the speed of these algorithms for complex multiplication operations by 1.33 times, and in the number of complex addition operations by 1.67 times. The MVS device software, built using the proposed methods, made it possible to obtain good convergence of the results for assessing the particle size distribution of crushed coke samples with laboratory assessments. Thus, the maximum mean error of MVS device in assessing the size of crushed coke is 3.37%, and the maximum error for all measurement classes did not exceed 6.9%.

5. Acknowledgments

The work was performed under state contract 3170ГС1/48564, grant from the FASIE.

References

[1] Maiti A, Chakravarty D, Biswas K and Halder A 2017 Development of a mass model in estimating weight-wise particle size distribution using digital image processing *Int. J. Mining Sci. and Techn.* **27** 435–43
[2] Thurley M J and Ng K C 2005 Identifying, visualizing, and comparing regions in irregularly

IOP Conf. Series: Materials Science and Engineering **966** (2020) 012135 doi:10.1088/1757-899X/966/1/012135

spaced 3D surface data *Comp. Vis. Img. Und.* **98 (2)** 239-70
[3] Hurelchuluun I, Kruglov V N 2016 Industrial tests and modernization of GRANICS crushed ore particle size measurement system *Trans. of Int. Conf.: Scientific basics and practice of processing ores and raw materials* 261-5
[4] Hurelchuluun I, Morozov V V, Nikolaev T S, Kruglov V N 2019 The use of visiometric analysis of the particle size distribution of ore for automated control of the crushing process *Ores and Metals* **1** 67-73
[5] Gonzalez R C, Woods R E 2007 *Digital Image Processing* 3 ed. (Pearson) p 976
[6] Sonka M, Hlavac V and Boyle R 1999 *Image Processing, Analysis, and Machine Vision* (Milan Sonka - Brooks/Cole Publ. Company) p 770
[7] Pratt W K 2007 *Digital Image Processing: PIKS Scientific Inside* 4 ed. (New York: Wiley Interscience) p 812
[8] Rabiner L and Gould B 1978 *Theory and application of digital signal processing* (MIR) p 84