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Size Distribution Measurement of Coal Fragments Using Digital Imaging Processing

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Abstract

This paper focuses on the size distribution measurement of coal fragments by digital imaging processing. The fast and precise measurement of coal fragments, which is important to understand the crack propagation and energy dissipation process of coal failure, has not been achieved by previous research. In this paper, an image analysis method using MATLAB is proposed to measure fragment size distribution of coal fragments. The acquisition setup, analysis step and coding process for fragment size distribution measurement by digital imaging processing are introduced in detail. The statistical size distribution of coal fragments measured by image processing is compared with the theoretical distribution function and manual sieving result. This paper provides an innovative and efficient method for size distribution measurement in the study of coal failure process.

Keywords

Size Distribution Measurement, Coal Fragments, Digital Image Processing, MATLAB

1. Introduction

Coal fragmentation is a common physical and mechanical phenomenon exists in the brittle failure of coal subject to static, impact and dynamic loads, during which coal fragments with difference size can be generated. The analysing of fragment size distribution (FSD) will contribute to understanding the energy dissipation characteristics and stress history of coal samples [1, 2]. Sieving is a traditional and indirect way to measure the statistical fragment distributions of solid fragments. Sieving method, which is cheap and easy, has been the main method for size determination [3].However, it has limitation on the sampling data due to the discrete diameters of the membrane [4]. Fernlund introduced Danish Box for the measurement of aggregate size [5]. However, this method is time-consuming as aggregates are measured one by one. Besides, calliper has the same shortness with Danish Box as well. Sedimentation method has been adopted to analysis pulverized solid particles [6]. But the analysis process of sedimentation method is costly as professional instruments need to be used to achieve the analysis. Hence, more reliable and efficient way need to be used for the measurement of fragment size distribution.

In the last few years, measurement process, especially the fast and accurate image processing method for determining the size and shape of solids, has been well-developed based on the wide application of computer science. With the advancement of digital image acquisition equipment, low cost software package and mathematical analysis algorithm, different methods were used by some researchers to measure the size distribution of solid particles [7, 8]. Tafesse et al. described the procedure of image processing for grain size measurement and compared the image processed data with the results got by mechanical sieving [6]. Tafesse' study didn't demonstrate the efficiency of this method as each image contained no more than 15 particles. Fernlund introduced the determination of aggregate size through image processing [9]. However, the detailed procedure of image processing has not been mentioned in his research. Kumara et al. adopted image processing to measure the size of gravel and got the gradation curve by ellipse shape assumption [10]. The size range of selected gravel in his research was 0-20 mm. Different with gravel, the brittle failure of coal samples can generate thousands of debris range from several millimetre to tens millimetre during laboratory uniaxial compression tests, which increases the challenge of accuracy and efficiency of image processing. Influenced by the physical properties of materials, the instruments setup and analysis algorithm for measurement of coal are not same with other geo-materials. Nevertheless, the application of image processing for size distribution measurement of coal fragments has never been touched by previous research.

In this paper, we aim at demonstrating the feasibility of measurement of coal fragments size distribution by using imaging processing technic. The image analysis is achieved by application of MATLAB. The image acquisition and analysis procedures are described in Section 2. In Section 3, the statistical size distribution of coal fragments measured by image processing is compared with the fractal distribution function and manual sieving results.

2. Materials and methods

2.1 Image acquisition

The coal fragments generated by uniaxial compression test were separated into several regimes through manual sieving (Figure 1) for further image processing. The sieve adopted in this study has four mesh sizes including $d = 2.5, 5, 10$ and 20 mm.

Figure 1 Manual Sieving with Different Mesh Size

To get high-quality image for analysis, a high-resolution Nikon single-lens camera was used to capture the image of coal fragments. As shown in Figure 2, the camera was remotely controlled by mobile phone through wireless connection to guarantee the consistency in camera setting and position. During the image acquisition, a white canvas with the sample number and size range was placed under coal fragments to create a luminous background. Fragments were evenly arranged on the canvas to avoid touching and overlapping each other, which is helpful to getting the distinct boundaries of each fragment hence to reducing unnecessary image processing techniques. Photographing was conducted in the room without light disturbance in order to minimize the error caused by shading and tilting effect [6]. Additional light needed to be applied if there were shadows caused by indoor light conditions.

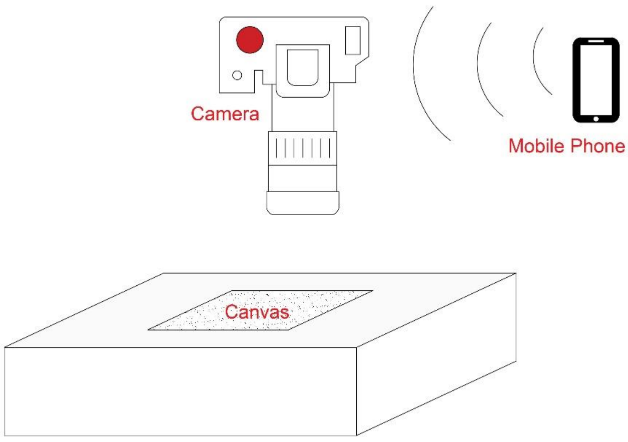

Figure 2 Schematic Diagram of Image Acquisition Setup

2.2 Image Analysis

The image analysis process was done by image processing toolbar of MATLAB which provides a comprehensive set of algorithms and workflow apps for image processing, analysis, visualization and algorithm development [11]. The image analysis procedures adopted in this paper are shown in Figure 3. The image was read in colour by image reading code, and then transferred into grayscale binary image by image binarization. In this paper, watershed segmentation, which is a powerful tool used to detect and distinguishing touching debris in images [12], was used to detected edges on the binary image to separate coal fragments in an image. Watershed segmentation contains three main steps: computing of segmentation function, marking of segmentation objects and computing foreground and background markers. These image processing operations including image reading, image binarization and watershed segmentation are called image pre-processing. The result of image after every step is shown in Figure 4. Depending on the quality of the pre-processed image judged based on the separation situation of fragments boundary, number of noise elimination, image sharpening, contract enhancement and edge-preserving filtering would be decided. Then the image pixel was transferred into real-world physical unit through scale calibration.

As shown in Figure 5, the fragment size can be represented by intermediate axis as ellipsoid shape is generally used to represent the irregular shape of fragments [10, 13]. The shorter axis, which is the thickness of fragments, cannot be directly measured by 2-D images.

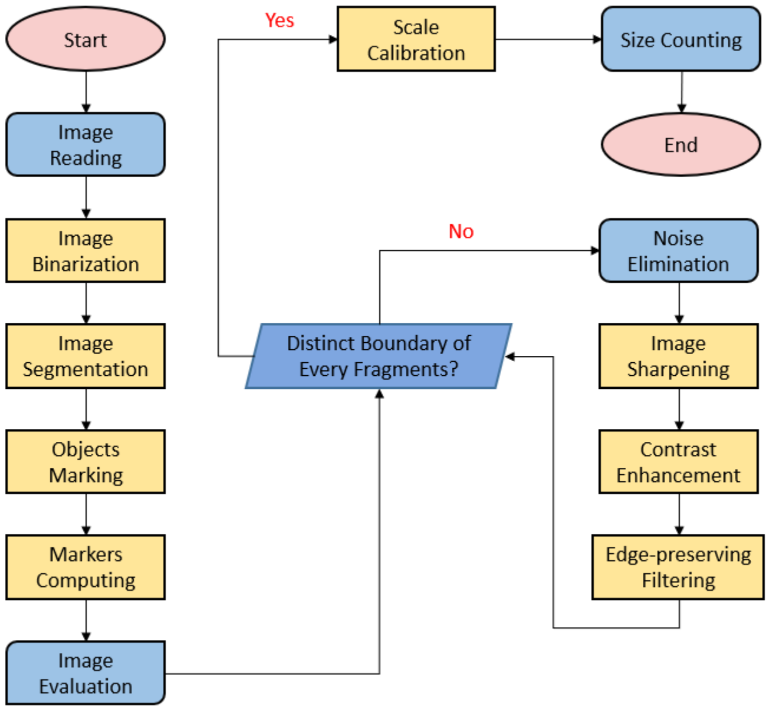

Figure 3 Flow Chart of Image Analysis Process

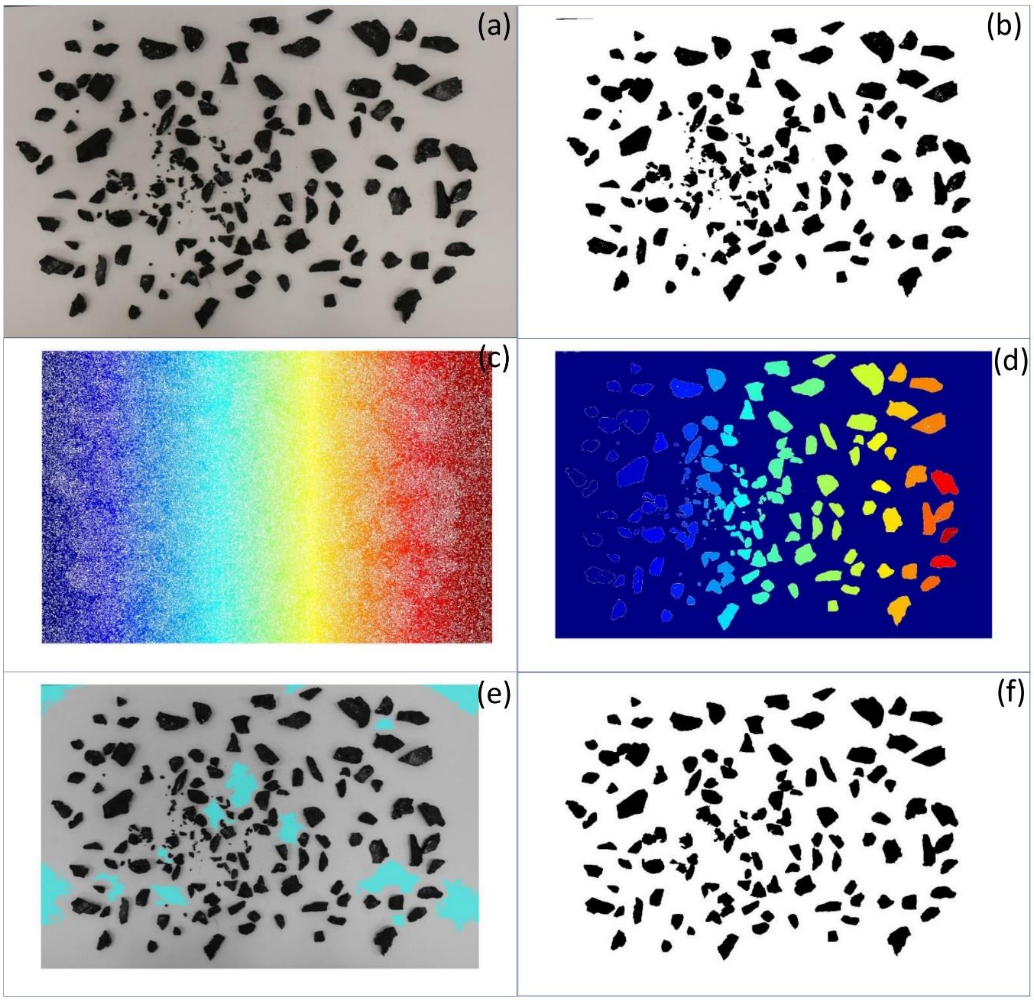

Figure 4 Image Pre-processing. (a) Original image, (b) binary image, (c) watershed segmentation, (d) foreground objects marking, (e) background markers computing, (f) final image

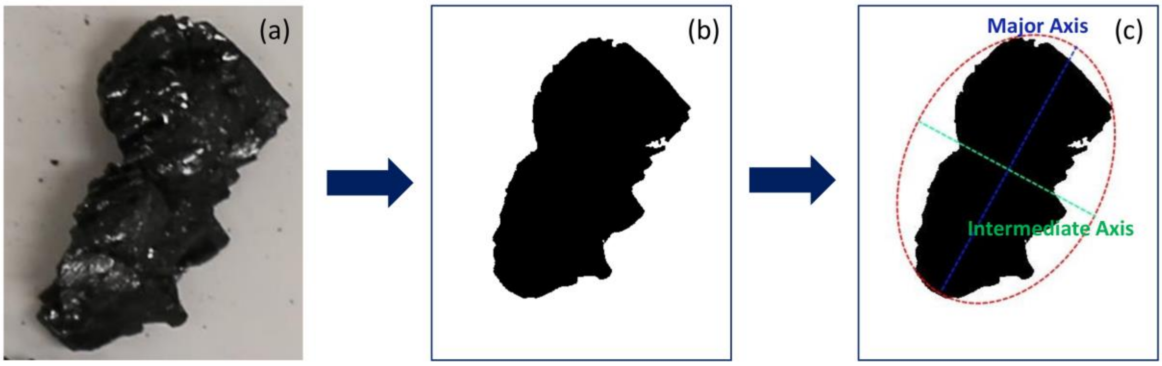

Figure 5 Size Measurement of a Fragment. (a) Original image, (b) binary image, (c) equivalent area ellipse.

3. Results and discussion

The weight of fragments was determined using the results of image analysis. As shown in Figure 5, the major axis and intermediate axis can be directly observed from 2D images. Weight of an ellipsoid, W, can be given as [10]:

$$W = \rho \times \frac{4}{3}\pi \times \frac{a}{2} \times \frac{b}{2} \times \frac{c}{2} \tag{1}$$

Where ρ is density of coal, a is major axis, b is intermediate axis and c is minor axis.

Experimental study done by Li et al. [14] has shown that the ratio minor axis and intermediate axis of coal fragments resulting from uniaxial compression load is close to 1. Therefore, the weight of fragments could be determined by:

$$W = \rho \times \frac{4}{3}\pi \times \frac{a}{2} \times \frac{b}{2} \times \frac{b}{2} \tag{2}$$

The uniaxial compression loading tests of four cylindrical coal samples with 50 mm diameter and 100 mm length were conducted in laboratory to get coal fragments after brittle failure. The test procedures had been detailed introduced in previous publication [15]. Fragment size distribution (FSD) of shattered coal samples was firstly manually sieved by mesh, and then analysed by image processing method introduced above. As shown in Figure 6, the binary image was analysed by MATLAB image processing toolbar and each fragment was taken as ellipsoid characterized by major axis, intermediate axis and minor axis. The length of major axis and intermediate axis of every fragment could be directly measured by software and the length of minor axis was same with intermediate axis in this paper. The density of coal samples measured in laboratory was 1.41 t/m^3. The weight of every fragment could be calculated based on equation (2).

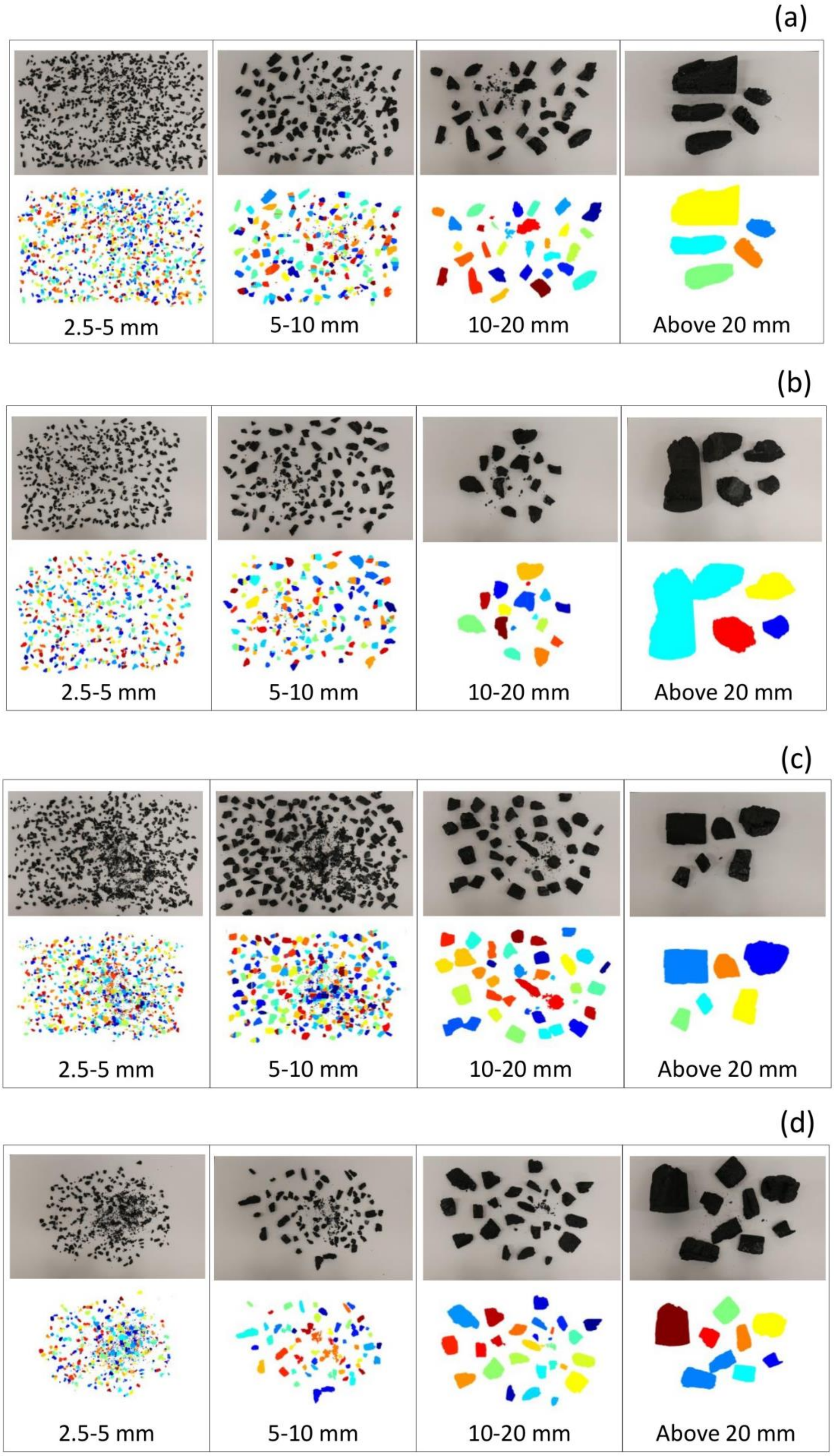
(a)
2.5-5 mm
5-10 mm
10-20 mm
Above 20 mm
(b)
2.5-5 mm
5-10 mm
10-20 mm
Above 20 mm
(c)
2.5-5 mm
5-10 mm
10-20 mm
Above 20 mm
(d)
2.5-5 mm
5-10 mm
10-20 mm
Above 20 mm

Figure 6 Original and processed image of coal fragments with different size. (a) Original and processed image of sample A1, (b) Original and processed image of sample A2, (c) Original and processed image of sample A3, (d) Original and processed image of sample A4

Besides, fragmentation distribution of coal samples generated by uniaxial compression loading tests has been described by the exponential function $F(d)$ that represents the statistical distribution of the fragments number frequency and the cumulative distribution function is named fractal model [16, 17]:

$$F(d) = (\frac{d}{d_{max}})^{(3-n)} \tag{3}$$

Where $F(d)$ is the cumulative mass fraction of the fragments smaller than size d, d_{max} is the maximum size of FSD and n is the fractal dimension of FSD, which is related to coal properties.

To demonstrate the accuracy of size distribution measurement of coal fragments using digital imaging processing, the image-processed, manual sieved and fractal modelled cumulative distribution curves of these four samples are shown in Figure 7. As shown in Figure 8, the image-processed results work even better than fractal model proposed by previous research as the RMS (Root Mean Square) error between manual sieving curve and image processing curve is lower.

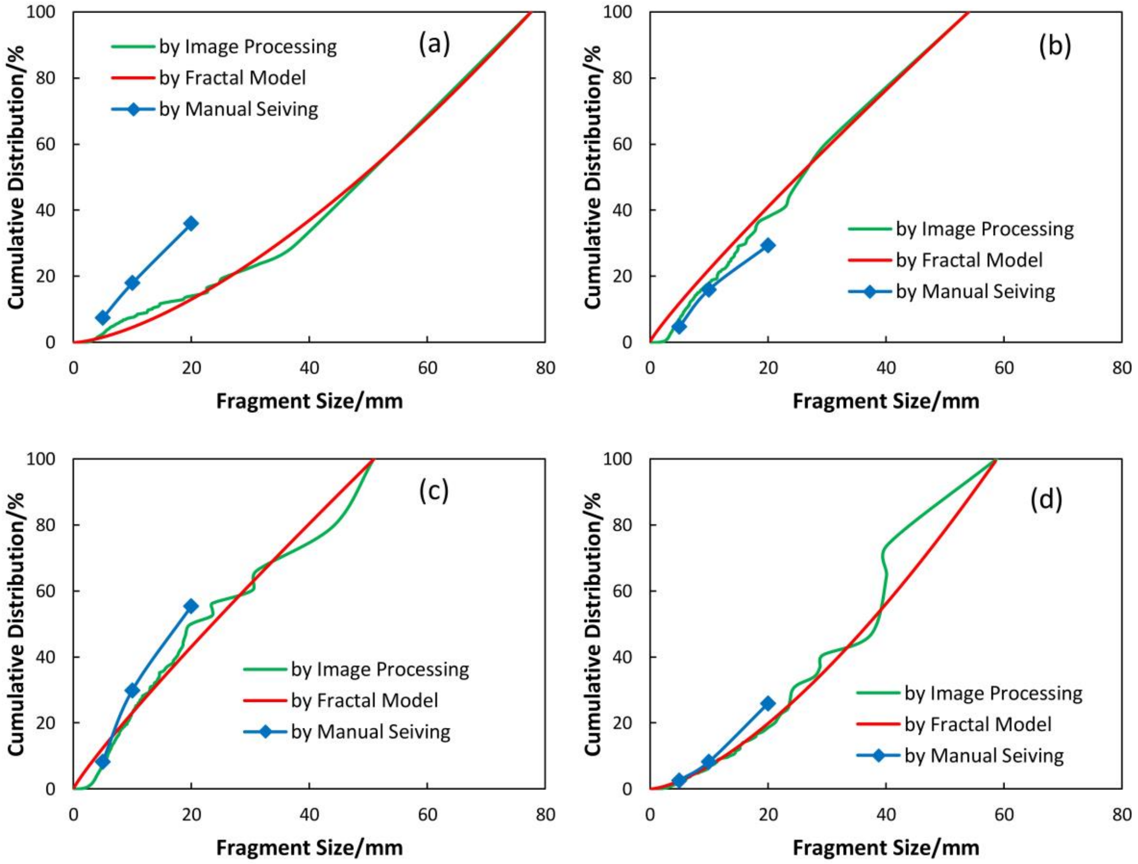

Figure 7 Cumulative Fragment Size Distribution of Coal Samples and Fitting Distribution. (a) Cumulative Size Distribution of Sample A1, (b) Cumulative Size Distribution of Sample A2, (c) Cumulative Size Distribution of Sample A3, (d) Cumulative Size Distribution of Sample A4.

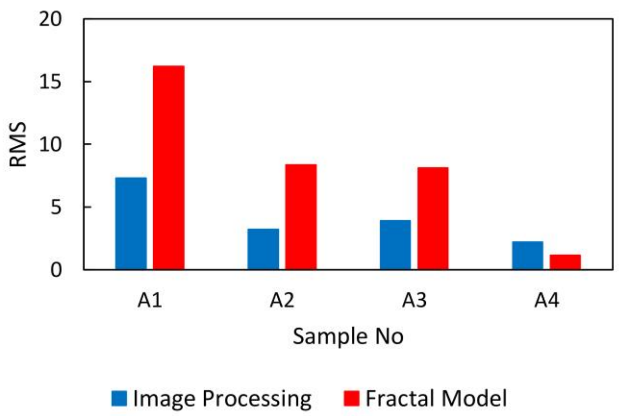

Figure 8. RMS of Image Processing and Fractal Model

4. Conclusions

The brittle failure of coal samples can generate thousands of debris range from several millimetre to tens millimetre during laboratory uniaxial compression tests. However, the fast and precise measurement of coal fragments, which is important to understand the crack propagation and energy dissipation process of coal failure, has not been achieved by previous research. This paper proposed the application of image processing technique in measurement of coal fragments generated by uniaxial compression tests.

The image processing method based on MATLAB image process toolbar is proposed in this paper. The acquisition setup, analysis step and coding process for image processing are introduced in detail. The watershed method is adopted for fragment segmentation in this paper. It has been shown by the contrast between images before and after image processing that the image processing method proposed in this paper is suitable for coal fragments measurement.

In this paper, the fragment in the image is taken as ellipsoid characterized by major axis, intermediate axis and minor axis. And the image processed cumulative distribution of coal samples is got based on image analysis results, ellipsoid volume equation and intermediate–minor axis value relationship. The comparisons between image-processed, manual sieved and fractal modelled cumulative distribution curves shown in Figure 7 demonstrates that digital image processing is an efficient and accurate tool to measure the size distribution of coal fragments.

The operation speed of image processing was of low speed as coal fragments were separated into several regimes through manual sieving for image processing. Manual sieving is not essential any more as this research has demonstrate the feasibility of coal FSD measurement through image processing. In the future application, only one picture needs to be taken and processed, which can save more time of the image acquisition process. The image analysis was based on MATLAB coding and the data will be stored automatically. But the code calling and data analysing are finished with human interaction. It is highly possible to make all these operations more intelligent by the application of programming, AI and deep learning.

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Declaration of Competing Interest

The authors declare no conflict of interest.

Reference

[1] D.Q. Liu, D.J. Li, F. Zhao, C.C. Wang, Fragmentation characteristics analysis of sandstone fragments based on impact rockburst test, Journal of Rock Mechanics and Geotechnical Engineering, 6 (2014) 251-256.
[2] X.H. Yang, T. Ren, L.H. Tan, Estimation of average ejection velocity generated by rib burst under compression load, International Journal of Rock Mechanics and Mining Sciences, 128 (2020) 104277.
[3] P. Bowen, Particle size distribution measurement from millimeters to nanometers and from rods to platelets, Journal of Dispersion Science and Technology, 23 (2002) 631-662.
[4] X.F. Li, H.B. Li, Q.B. Zhang, J.L. Jiang, J. Zhao, Dynamic fragmentation of rock material: Characteristic size, fragment distribution and pulverization law, Engineering Fracture Mechanics, 199 (2018) 739-759.
[5] J.M.R. Fernlund, Image analysis method for determining 3-D size distribution of coarse aggregates, Bulletin of Engineering Geology and the Environment, 64 (2005) 159-166.
[6] S. Tafesse, J.M.R. Fernlund, F. Bergholm, Digital sieving-Matlab based 3-D image analysis, Engineering Geology, 137 (2012) 74-84.
[7] H. Peregrina-Barreto, I.R. Terol-Villalobos, J.J. Rangel-Magdaleno, A.M. Herrera-Navarro, L.A. Morales-Hernández, F. Manríquez-Guerrero, Automatic grain size determination in microstructures using image processing, Measurement, 46 (2013) 249-258.
[8] L.C. Wu, C. Yu, Powder particle size measurement with digital image processing using Matlab, Advanced Materials Research, Trans Tech Publ, 2012, pp. 589-593.
[9] J.M.R. Fernlund, Image analysis method for determining 3-D shape of coarse aggregate, Cement and Concrete Research, 35 (2005) 1629-1637.
[10] G.H.A. Kumara, K. Hayano, K. Ogiwara, Image analysis techniques on evaluation of particle size distribution of gravel, Int. J. Geomate, 3 (2012) 290-297.
[11] H. Krishnan, K. Priyadharshini, M. Gowsic, N. Mahesh, S. Vijayananth, P. Sudhakar, Plant disease analysis using image processing in MATLAB, 2019 IEEE International Conference on System, Computation, Automation and Networking (ICSCAN), IEEE, 2019, pp. 1-3.
[12] A. Rabbani, S. Ayatollahi, Comparing three image processing algorithms to estimate the grain-size distribution of porous rocks from binary 2D images and sensitivity analysis of the grain overlapping degree, Special Topics & Reviews in Porous Media: An International Journal, 6 (2015).

[13] E. Hamzeloo, M. Massinaei, N. Mehrshad, Estimation of particle size distribution on an industrial conveyor belt using image analysis and neural networks, Powder Technology, 261 (2014) 185-190.
[14] Y.Y. Li, S.C. Zhang, X. Zhang, Classification and fractal characteristics of coal rock fragments under uniaxial cyclic loading conditions, Arabian Journal of Geosciences, 11 (2018) 201.
[15] X.H. Yang, T. Ren, L.H. Tan, A. Remennikov, X.Q. He, Developing coal burst propensity index method for Australian coal mines, International Journal of Mining Science and Technology, (2018).
[16] R.d. Peng, Y. Ju, J.G. Wang, H.p. Xie, F. Gao, L.t. Mao, Energy dissipation and release during coal failure under conventional triaxial compression, Rock Mechanics and Rock Engineering, 48 (2015) 509-526.
[17] J.X. Liu, H. Zhang, J.G. Liu, X.M. Jiang, Comminution theory of superfine pulverized coal based on fractal analysis of aggregate structures, Energy Fuels, 30 (2016) 10244-10252.