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Original Research Paper

Image analysis algorithm and verification for on-line molecular sieve size and shape inspection

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ABSTRACT

An online machine vision inspection method is proposed to implement feedback control of molecular sieve growth process in rotary drum granulation. An experimental platform, comprising of a high-resolution digital camera and an image analysis system, has been developed to confirm the validity of the method on particle size distribution (PSD) and sphericity measurements. Experiments were performed with non-uniform molecular sieve particles (1–3 mm diameter) obtained from production line. The particle images are first obtained through digital camera and are then processed by image analysis system. After separating the overlap particles and removing non-target particles of the images, the molecular sieve size and shape are computed in less than 0.9 s. The validity of the size measuring accuracy is confirmed through comparing with the results from micrometer. The experimental results show that the repetitive precision of the proposed inspection system is about ±1%, the diameter measurement error between image method and micrometer is about ±3%, single image inspection speed is around 0.9 s/frame. The proposed method is reliable to provide feedback information for control system in rotary drum granulation.

Introduction

Molecular sieve is a kind of spherical silica particles used in catalysis, adsorption and separation process. Particle size and PSD have great impact on molecular sieve's chemical and mechanical properties. In addition, particles sphericity is proportional to its packing density [1]. These physical properties would also influence the performance of molecular sieve composition [2]. Therefore, molecular sieve production has high requirements on particle size and sphericity accuracy. Thus, accurate monitoring particle growth process is of great significance for ensuring quality of the molecular sieve in industrial production.

The classical techniques of particle size measurement involves sieving, sedimentation and laser diffraction [3,4]. Sieving is one of the oldest particle size distribution analysis techniques [5] and is widely used in many countries for its high reliability and repeatability. However, this method has some shortcomings. For instance, whether a particle could pass through the sieve depends on the minimum particle diameter, which would influence the diameter measurement accuracy for sieving method. Sedimentation method is not suitable for industrial application because of lower measuring efficiency, although its results are generally recognized [6]. Laser diffraction has similar measuring efficiency and accuracy to those of image analysis [3], but the former cannot measure sphericity since the objects are assumed as ideal spheres [7]. The image analysis technique that based on digital particle image analysis [8] has significant improvement on economy and efficiency, and enlargement in the number of measurable parameters. It would be implemented easily in industrial production since it provides the fast non-contact particles size and shape measurement. Furthermore, it has the same reliability as the sieving method on diameter measurement [9]. So far some commercial particle inspection instruments are available. But those equipments works under experimental environment, which hardly realize particle automatic inspection and information feedback for on-line inspection system. Several on-line particle monitoring methods have been developed. Ilkay Talu et al. [10] have proposed a particle growth monitoring method by detecting powder stress fluctuations in granulator. Stephen Tallon and Davies [11] have developed an in-line density measurement device to monitor the local bulk density on mixing process in a rotating drum. However, these studies could neither directly monitor particle growth nor measure particle shape.

In this work, an online machine vision inspection method is proposed to directly monitor particle growth in rotary drum gran-

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ulator. An experimental platform was set up to demonstrate the feasibility of the method on industrial practice. Experimental results show that the platform has high speed and precision on particle inspection in the range of 1–3 mm.

Experimental set-up

The molecular sieve particle size inspection system consists of hardware and software systems. The hardware system includes the image acquisition module, the image processing and data storage module and the data output module (see Fig. 1). A high-resolution digital camera (Canon EOS 550D, Canon EF 50 mm f/1.8 II fixed focus lens) is utilized as image acquisition device, as shown in Fig. 2. On the measurement process, molecular sieve particles are randomly distributed on the backlighting panel first and then the particle images are captured and transmitted to computer. After a series of processing by developed image analysis software, the particle's geometrical information would be outputted and be stored at the same time.

To ensure the effectiveness of the measurement data, the parameters were compared between digital camera used in experiments and industrial camera. The experimental platform scaling factor that computed by Eq. (1) is 0.0019 mm^2/pixel at 500 mm shooting distance. When the lens is changed into object side telecentric lens (e.g., OPTO TC2396) and is equipped with a 2/3 in. 5.5 million pixel CCD in industrial application, the scaling factor of that platform is 0.0012 mm^2/pixel. Hence the industrial camera has higher image quality in this state. The scaling factor can be expressed as:

$$K = S/P \tag{1}$$

where S is the actual area, P is the image pixel values.

Calibration is the necessary step to transfer the image pixel into a real-world physical unit. The scaling factor is obtained by measuring a steel ball in our whole experiments whose diameter is 3 mm with 2.5 μm variation ball diameter and 2.5 deviation from spherical form.

Image processing and analysis

As is shown in Fig. 3, the image analysis algorithm is composed of image preprocessing, thresholding, particle partitioning and particle measuring etc. Particle's feature information such as particle size, roundness, sphericity, and PSD can be obtained after analyzing by the software.

Image preprocessing

On image capturing and transmitting process, image quality is easily influenced by complexity industrial environment, for example, the lens contamination and electromagnetic interference, which decrease the image quality. To reduce that influence and enhance the image's regional feature, the median filtering are utilized [12]:

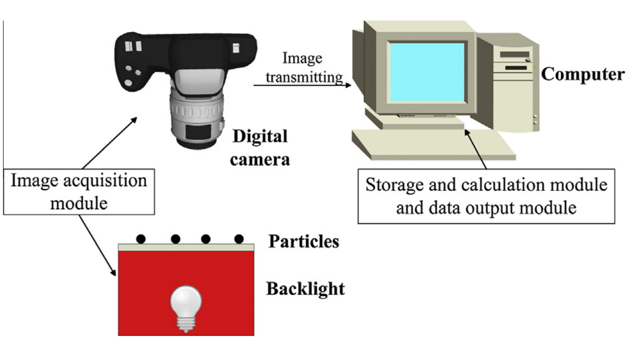

Fig. 1. Structure of the experimental platform.

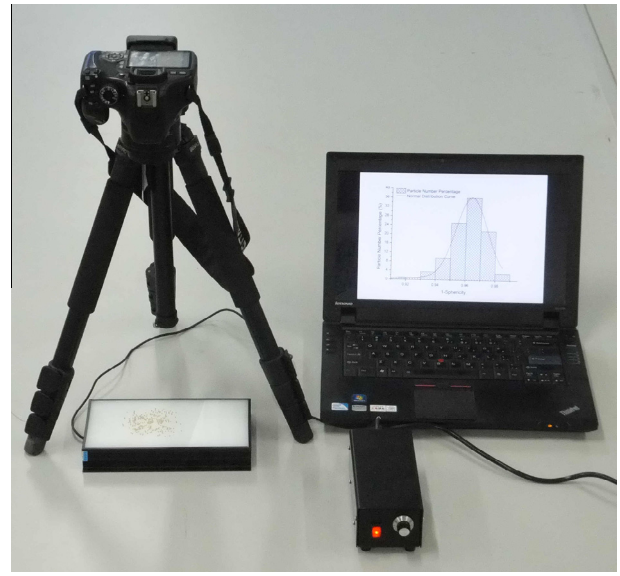

Fig. 2. Experimental equipment.

$$g(x,y) = med\{h(x-k, y-l), (k, l \in W)\} \tag{2}$$

where h (x, y), g (x, y) are the original image and processed image separately, W is a two-dimensional template. Median filtering has higher computational complexity [13]. However, through quickening the kernel update by increasing or decreasing the pixels of the image column histogram, the computational complexity can be reduced from O ($r^2\log r$) to O (1) [14].

Threshold processing

Threshold processing is the process of converting a grayscale image into a binary image, i.e. converting image into a black and white one represented by values 0 and 1. When the interesting pixel values are greater than or equal to the threshold value q, they are set to 1 and the other points are set to 0. The binary image $B(x, y)$ can be expressed by Eq. (3). The raw image, as shown in Fig. 4a, is converted into binary image in which foreground is separated from background, as shown in Fig. 4b.

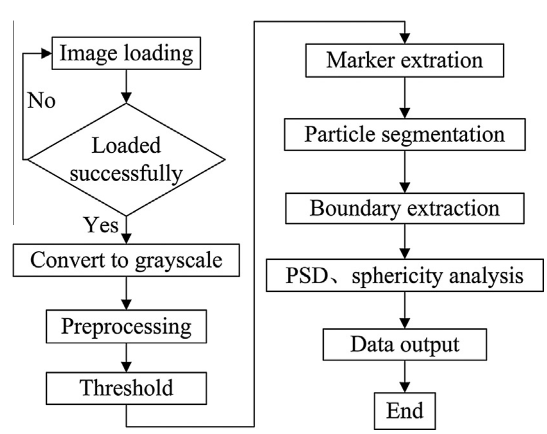

Fig. 3. The flow chart for image processing and analysis.