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Recognition of Blast Furnace Gas Flow Center Distribution Based on Infrared Image Processing

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Abstract: To address the problems about the difficulty in accurate recognition of distribution features of gas flow center at blast furnace throat and determine the relationship between gas flow center distribution and gas utilization rate, a method for recognizing distribution features of blast furnace gas flow center was proposed based on infrared image processing, and distribution features of blast furnace gas flow center and corresponding gas utilization rates were categorized by using fuzzy C-means clustering and statistical methods. A concept of gas flow center offset was introduced. The results showed that, when the percentage of gas flow center without offset exceeded 85%, the average blast furnace gas utilization rate was as high as 41%; when the percentage of gas flow center without offset exceeded 50%, the gas utilization rate was primarily the center gas utilization rate, and exhibited a positive correlation with no center offset degree; when the percentage of gas flow center without offset was below 50% but the sum of the percentage of gas flow center without offset and that of gas flow center with small offset exceeded 86%, the gas utilization rate depended on both the center and the edges, and was primarily the edge gas utilization rate. The method proposed was able to accurately and effectively recognize gas flow center distribution state and the relationship between it and gas utilization rate, providing evidence in favor of on-line blast furnace control.

Key words: infrared image processing; gas flow center recognition; gas utilization rate; fuzzy C-means clustering

Blast furnace production is a series of complex physical, chemical and heat transfer reactions running under high temperature and high pressure conditions[1]. Since internal smelting is a typical dark-box operation[2-4], it is very difficult to achieve accurate real-time positioning and control of gas flow center distribution at blast furnace throat. Besides, a reasonable gas flow center distribution is an important condition that ensures steady descending of burden material and normal running of chemical reactions and heat exchange in the blast furnace[5-7], and an important route for smooth and stable running, energy conservation and consumption reduction, production increase and quality improvement of the blast furnace. Therefore, to have accurate real-time information of gas flow center distribution and to determine the relationship between gas flow center distribution features and gas utilization rate are vital to blast furnace production control.

Conventional blast furnace operation is adjusted and controlled by the furnace superintendent through empirical judgment of the blast furnace gas flow distribution. In recent years, many scholars have studied gas flow recognition methods, primarily including (1) building a mechanism model for gas flow distribution by the rules of gas moving in burden layers[8,9], which is very complicated in computation and too difficult to obtain the rules of burden layer motion; (2) building a neural network model based on cross temperature measurement data in order to recognize blast furnace gas flow distribution mode[10,11], which primarily recognizes burden surface temperature and is not able to reflect the distribution location of gas flow center accurately and in real-time; (3) the laser[12] and ultrasonic[13] methods which are used to test the shape and temperature of the burden

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surface, but regardless of the gas flow distribution; (4) using infrared camera to observe development of gas flow over burden surface in modern blast furnaces along with developing infrared technology[14,15]. Wu et al.[16] conducted data fusion with infrared images and cross temperature measurements, mainly studied gas flow development and distribution in terms of gas flow index, but had no in-depth study on specific distribution features of gas flow center and the influences of such center distribution on blast furnace production.

In this paper, a 2 500 m^3 blast furnace was the subject of present study (with raw material from Bayan Obo Mine). Infrared video data of production was acquired on-line for 1 month (720 h), and through batch processing of massive infrared image data, 3 600 frames of infrared images of gas flow per hour were obtained. The distribution features of gas flow center every hour were recognized (i. e., 720 h, 3 600 frames of image per hour) and statistically quantified, and with taking cross temperature measurement data into account, the fuzzy C-means clustering method was employed to categorize blast furnace gas flow center distribution and gas utilization rate, and to determine their relationship.

1 Image Processing

It can be known from infrared imaging principle that the intensity of infrared light is proportional to temperature. It can be known from the radial distribution of gas flow temperature at blast furnace throat that, the stronger the gas flow, the higher the temperature and the larger the bright zone of film; the weaker the gas flow, the lower the temperature, and consequentially the bright zone of image is very small or even absent. Thereby the infrared images were recognized according to this principle.

1.1 Image filtering

Since blast furnace iron smelting is a highly complex process, infrared images easily produce noises and pulse interference which are detrimental to extraction of image features, so they have to be filtered. Image filtering methods include Gaussian filtering, median filtering and mean filtering; as Gaussian filtering is mainly used to filter Gaussian noise while individual median or mean filtering has no significant effect, the images were mainly processed with a combination of mean filtering[17] and median filtering[18] in this paper. The specific procedure is as follows:

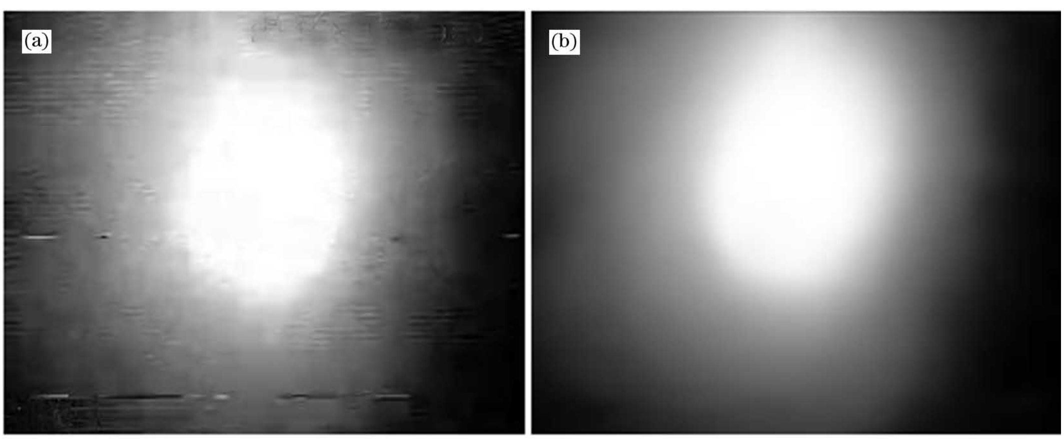
Step 1 Select one infrared image and thus acquire $g(x,y)$, where x is the row number of an image, and y is column number of the image.

Step 2 Process the infrared image $g(x,y)$ using mean filtering and save it to the image $g_1(x,y)$, i. e.

$$g_1(x,y)=\frac{1}{9}\sum_{(x,y)\in(3\times3)}g(x,y) \tag{1}$$

Step 3 For the mean-filtered image, $g_1(x,y)$ run median filtering and save it to the image $f(x,y)$, where the value of $f(x,y)$ is the grayscale of the pixel (x,y).

Figs. 1(a) and 1(b) are the original image and the filtered image respectively. After mean and median filtering of an image, not only some glitches and salt-and-pepper noise are removed, but also the image is smoothed, thus overcoming stochastic interference effectively and retaining image details and edges relatively well; moreover, the burden surface temperature information is preserved in the form of grayscale image, providing the basis for image feature extraction.



(a) Original grayscale image; (b) Mean and median filtered image.

Fig. 1 Image filtering