Abstract

The status of the blast tuyere from monitoring video is usually estimated by artificial observation, but it is difficult to ensure the consistency and uniformity of the flow of pulverized coal injection. In this paper, image analysis of video recordings is presented and discussed as a novel means to estimate the instantaneous coal flow. Appropriate feature extraction algorithms based on coal injection image of video are the key technology in this method. According to the field process characteristics and two-dimensional image of coal group, feature extraction algorithm based on area statistical is proposed to estimate the flow. In addition, in order to achieve the estimation of the space volume of coal group, three kinds of volume feature extraction algorithm (Grey weighted method, the equivalent ellipse method and the axis rotation method) are explored. The experiment shows that these algorithms can reflect the flow changes accurately, and the errors of these algorithms are all within ±15%, meeting the requirements of the field well.

Keywords: Blast Furnace; Tuyere; Image Analysis; Coal Injection Statement; Digital Image Processing.

1. Introduction

With the increasing rate of pulverized coal injection, the security and stability of the pulverized coal injection system has become more and more important [1]. Monitoring the status of branch pipes of pulverized coal injection
into blast furnace is indispensable to ensure smooth and stable operation in blast furnace and a high coal rate injection, which can also reduce the smelting costs.

At present, the monitoring methods of branch state of blowing pulverized coal injection mainly include temperature difference method, optical detection and capacitance detection, monitoring the state of branch state in the blowing process. When the temperature of the blast furnace pulverized coal injection system is higher than the ambient temperature and also higher than the temperature of compressed air passing by dry-cold dehydration, the temperature difference method can be applied. Temperature detection method has certain applicability when branch pipes of blast furnace coal injection are under closed environment. However, for branch pipes of blast furnace coal injection under outdoor environment, some factors (such as wind, solar and season) make different effect on branch pipe of different position, resulting in the temperature difference difficult to summarize. Optical detection and capacitance detection also has not been actually used because of weak practicality and high cost [2-3].

This paper presents a video-based method to detect the coal injection state of tuyere in a blast furnace. This method establishes the relationship between the flow of pulverized coal injection and the features of the tuyere images with digital image processing technology based on analyzing the video images of the blast furnace monitoring cameras [4-5]. In this method, research on coal group image feature extraction algorithms is the core problem of the detection method.

In order to establish the relationship between the coal group and branch pipe flow, coal group image feature extraction algorithm based on area statistical method is proposed through analyzing the characteristics of the coal group. In addition, extraction algorithms such as grey weighted method, the equivalent ellipse method and the axis rotation method are researched to solve this problem. The experiments show that these extraction algorithms could reflect the flow changes of pulverized coal injection in the blast furnace accurately.

2. Coal injection image preprocessing and coal group object extraction

2.1. Region division of coal injection image

The placement of tuyere monitoring camera of single pipe is shown in Fig.1. The camera is placed in the position of the center line of the tuyere. Coal injection image is made up of three parts: spay gun, tuyere raceway and coal group, as shown in Fig.2. The main purpose of this paper is real-time tracking and extracting coal group image feature information to estimate the pulverized coal flow of the branch pipe.
2.2. Image enhancement and de-noising

In this paper, an image enhancement algorithm based on the combination of window gray stretching method and power transform is proposed for coal injection image enhancement processing [6]. Through the image processing results, this algorithm not only improves the image contrast, inhibits the halo phenomenon caused by high temperature in the blast furnace, but also has good adaptation and robustness.

In addition, an optimized compounding algorithm for image de-noising is designed, which combined the improved median filtering and mathematical morphology. Experiments show that, this algorithm removes image noise and preserves image edges, laying a good foundation for image object extraction and recognition. Results are shown in Fig.3.

2.3. Object extraction of coal group

For real-time tracking and extracting coal group image feature information to estimate the pulverized coal flow of the branch pipe, object extraction and recognition of coal group in the image of the pulverized coal injection should be analyzed and identified. Since gray of the spray gun region and coal group region is similar, the establishment algorithm of pulverized coal injection image real background is proposed, which combined with airbrush area detection [7-8]. Using background subtraction method, the coal group image segmentation and feature extraction have been done. The experiment based on the images obtained live using the method adopted in this paper can segment out the pulverized coal accurately for the different tuyeres. Through the above process, the final background template of pulverized coal injection image is shown in Fig. 4.
After the establishment of the background template of coal injection image, by constructing the difference between the de-noised image and the background template of coal injection image, the preliminary object region of coal group can be obtained. The accurate segmentation of the coal group is completed through the digital image processing on the obtained results. After processing, some of object extraction regions of coal groups are shown in the Fig.5.

Fig.5. The object extraction regions of coal groups.

3. Image feature extraction algorithms

According to the calculation formula of mass formula, the real-time mass flow of branch pipe of pulverized coal injection is equal to volume multiplied by the corresponding density of the coal group. Therefore, if the density of coal group is uniform, the volume of coal group should be extracted from image of pulverized coal injection accurately, in order to estimate the mass flow of pulverized coal injection based on the digital image processing correctly. However, because blast tuyere is the only place where could observe the state of coal injection. Method of the three-dimensional space reconstruction of coal group through analyzing image information from multicast camera is not desirable in the system of pulverized coal injection of the blast furnace. Therefore, how to acquire the optimal feature size information of the three-dimensional coal group through two-dimensional image is of great significance for the accurate estimation of the mass flow of pulverized coal injection. Four coal group image feature extraction algorithms are discussed in this part.

3.1. Area feature extraction algorithm

From the installation diagram of tuyere monitoring camera of the single branch pipe, it can be seen that the images from the monitoring camera record projection of a fixed angle. Information of space volume of coal group is shown as area of the two-dimensional image. Volume of coal group can be estimated by extracting area feature of the two-dimensional image [9]. In this algorithm, area of coal group can be calculated by add up the number of white pixel points in the object extraction region of coal group, and the number of white pixels represents the area of coal group. If the coal flow is stable in all directions, then the larger the volume of coal injection is, the greater mass flow of pulverized coal injection is.

3.2. Volume feature extraction algorithm

In order to achieve the estimation of the space volume of the coal group, three kinds of volume feature extraction algorithm are explored based on process characteristics and image feature of the coal group in this part.

- Estimation algorithm based on grey weighted

From the images of the coal groups, it can be seen that gray of the coal group in the object regions is not uniform, and the color of the coal group which is near the position of the center line of spray gun is deeper, and the gray value is smaller, In contrast, the color of the coal group located at the edge is lighter, and the gray value is larger, close to 255. In the calculation to estimate the mass flow of coal group, the characteristics of the coal group can’t be reflected accurately if the weight of pixel points is identical. Therefore, different weights are assigned to different gray values, that is, the pixel points of dark color and small gray value indicate that the mass flow of pulverized coal
injection in this region is large [10]. By this way, volume of coal group in the region can be estimated accurately. Although this method is reasonable in theory, there’s no strict rule for setting the weighs.

After repeated experiments, this paper proposed a method in which the grey values of pixel points are linear weighted to set the weights, so as to estimate the volume of coal group. In this method, the weights are assigned through the maximum and the minimum gray value in images. Smaller gray value of pixel points is assigned greater weights, while for larger gray value smaller weights are used. If the grey value of the image is R, the linear weighted function is as follows:

\[ f(R) = k \cdot R + b \]  

In the process of calculation, when all the gray value of the pixel points accumulates, the maximum gray value of pixel points makes minimum contribution to the accumulation, namely the pixel sets a minimum weight. In contrast, the minimum gray value of pixel points makes the greatest contribution to the accumulation, namely the pixel sets a maximum weight. Although this paper presents the weights calculation method of linear weighted, it doesn’t mean that this method is the optimal method for estimating weights, and this paper makes a preliminary discussion and attempt on this method. The gray image of coal group is acquired through processing the object extraction region, as shown in Fig.6. Weights of pixel points can be obtained according to the gray value of pixel points through the weights calculation method of linear weighted, then the pixel value is add up, and the volume can be estimated approximately through the cumulative sum.

Fig.6. Extraction of the coal group gray image. (a) Original image; (b) Object extraction region; (c) Gray image.

- Estimation algorithm based on equivalent ellipse
- ...

In the absence of multicast camera, object extraction region fitting a standard shape is a simple method to estimate the volume of the coal group. Although the shape and size of coal group change with time passing by, the basic shape of object extraction regions is very close to the ellipse according to the obtained shape information of coal group. Therefore, the ellipse which has the similar normal centre distance of two orders with the object region can be used to fit the region of coal group. In this way, the coal group can be seen as an ellipsoid in space, volume of coal group is estimated approximately by calculating the volume of the ellipsoid.

The separated images of coal group can be seen as a particle system (grey value represented by mass). If the number of particle in the particle system is N, mass value of all the particles is equal to 1 due to the same gray value of every pixel point, and coordinates of all the particles are \((x_1, y_1)\) to \((x_N, y_N)\) successively. If the rotation axis \(L\) passes by the origin of the coordinate system, the direction cosine of \(L\) are \(\alpha\) and \(\beta\) respectively [11]. The equation of moment of inertia for the particle system can be expressed as follows:

\[ I = A\alpha^2 + B\beta^2 - 2H\alpha\beta, (A = \sum_{i=1}^{N} x_i^2, B = \sum_{i=1}^{N} y_i^2, H = \sum_{i=1}^{N} x_i y_i) \]  

\(H\) is called product of inertia. If the quadric surface regards the origin as the centre, and regards the Oxy plane as section, then Eq.(2) becomes as follows:
As can be seen, this formula can be expressed as elliptic equation whose centre is the origin of coordinates. If \( r \) indicates the vector which is from the origin to a point on the curve, the direction cosine of it are \( \alpha \) and \( \beta \), and the vector norm is 1. Then \( x=r\alpha \), \( y=r\beta \) are substitute into Eq.(3), result is as follows:

\[
r^2(A\alpha^2+B\beta^2-H\alpha\beta)=1
\]

By comparing Eq.(3) and Eq.(4), it shows that the equation of moment of inertia for the particle system is consistent with the elliptic equation in the expression form. Thus, each object extraction region can obtain a corresponding ellipse and its equation of moment of inertia is consistent with the elliptic equation. If the density is identical in the region and their moment of inertia are the same, so the parameters of the elliptic equation can reflect the characteristics of the object region. The geometric model of the inertia ellipse is shown in Fig.7. By calculation, two semi-axes of the ellipse are shown as Eq.(5) and Eq.(6)

In this algorithm, the volume of the ellipsoid which corresponds to a coal group can be calculated according to Eq.(7), and the result is also the volume of the coal group.

\[
\text{volume} = \frac{4}{3} \pi p^2 q
\]

### 3.3. Estimation algorithm based on axis rotation

The acquired image from tuyere is the projection of the coal group region on a two-dimensional plane. In order to estimate the volume of coal group according to the projection, it is assumed that the shape of the actual coal group is generated by revolving the projection about its major axis. The volume of the coal group is obtained by calculating the volume of rotator. The direction angle of the major axis can be calculated according to the centre two-order moment, and the angle of the major axis rotates to the vertical direction. It is assumed that the spray gun injects pulverized coal in the vertical direction of the image. And the coal group can be seen as a rotator which rotates 360° around the axis at the vertical direction from the two-dimensional image of coal group, as shown in Fig.8. The projections of the rotated object region are accumulated in the vertical direction, and the central axis of this region is regarded as the rotation axis. In this way, the image is divided into two parts, and the volume of the coal group can
be obtained through calculating the volume of two parts respectively. The method to calculate volume the two parts is the same. The volume calculation of the left part is taken as an example as follows.

First, the number of white pixels in each row in the left part is preserved in a vector. Then every value in the vector is regarded as the radius of rotation, and the areas of left semicircles can be calculated. The volume of left region of coal group is obtained through are accumulating the areas of left semicircles. The same algorithm applies to the right region. The additive value of the volume of the two parts is the approximate volume of coal group.

![Fig.8. The schematic diagram of estimation algorithm based on axis rotation.](image)

### 4. Experiment results and analysis

As images come from cameras of different angles and the projections of the same coal group size will be different, so it is clearly unreasonable to verify the algorithms with the accumulated value of pulverized coal injection per hour in the branch. In order to eliminate this difference, the correctness of algorithms is verified by comparing ratio of the accumulated eigenvalue between two tuyeres in this paper. In this method, the hourly ratio of the accumulated eigenvalue should be kept in a fixed range with the passage of time. Because the method is in the discussion phase and there is no previous experience for reference, the error of the hourly ratio of the accumulated eigenvalue of each branch pipe is set to ±15% temporarily.

In experiment, collecting video on field is used to verify the four algorithms: area feature extraction algorithm, estimation algorithm based on grey weighted, estimation algorithm based on equivalent ellipse and estimation algorithm based on axis rotation (expressed by a, b, c and d successively in Table 1). The four algorithms are used to calculate the volume of the object extraction regions of coal groups, and then the hourly ratio of the accumulated eigenvalue in each branch pipe can be obtained and recorded. If the ratio per hour is $B_i$, and the ratio in each hour for a period of time is $B_1, B_2, \ldots, B_n$ respectively. In these ratios, the maximum value is denoted by $B_{\text{max}}$, the minimum value is denoted by $B_{\text{min}}$ and the average value is denoted by $\overline{B}$. The maximum uniform error is defined as Eq.(8). The standard deviation is used to compare the stability of the algorithms, and defined as Eq.(9).

\[
\varepsilon = \max \left( \frac{B_{\text{max}} - \overline{B}}{\overline{B}}, \frac{B_{\text{min}} - \overline{B}}{\overline{B}} \right)
\]  

\[\sigma = \sqrt{\frac{\sum_{i=1}^{n} (B_i - \overline{B})^2}{n}}\]

\[\text{(8)}\]

\[\text{(9)}\]

<table>
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<th>Method</th>
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Table 1. Errors of the four algorithms
Errors of the four algorithms are shown in above table. The experiments show that the errors of four algorithms stay at about 10%. In the four algorithms, the error of area feature extraction algorithm is 6.76% and the least of them, meeting the requirements on field well. Meanwhile, $\varepsilon$ and $\sigma$ of this algorithm are also the least of the four algorithms, showing the high applicability and stability of this algorithm. In the volume feature extraction algorithms, $\varepsilon$ of the algorithm based on grey weighted is smaller, but $\sigma$ of it is bigger. By analysis, it can be found that this algorithm is based on gray value of coal group and strongly affected by light. As a result, this algorithm is not so stable. The values of $\varepsilon$ and $\sigma$ are relatively bigger, and the main reason is the complexity and uncertainty of the coal group. Another reason is the limitation of estimating the volume of three-dimensional coal group with the two-dimensional image. Although errors of the two algorithms are relatively bigger, two possible models are proposed to calculate the volume of coal group, laying a good foundation for the further research.

5. Conclusion

This paper presents a new method to establish the relationship between the flow of pulverized coal injection and features of the tuyere images based on digital image processing technology. And the method of object extraction regions of coal groups is presented simply. And this paper presents and analyzes four algorithms to calculate the volume of coal group. Experiments show that errors of the four algorithms are within ±15%, meeting the requirements of the field well, laying a good base on further research.

References