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Investigation on the Feature Extraction from Sectional Image of Sinter Machine End and Its Classification

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ABSTRACT On the basis of analyzing the mechanism of sintering process , the primary features of the Sectional Image of Sinter Machine End (SISME) were presented. In order to describe the variation of sintering process completely and accurately by using SISME feature, the secondary features extracted by means of mathematical transformation. Testing the SISME secondary features on some SISME samples, it was proved that the features have a good classification effect on sinter quality.
KEY WORDS sinter, image processing, pattern recognition

The sectional image of sinter machine end contains a lot of information about sintering process and sinter quality. In practical production, it was always obtained by man's eyes, therefore a whole variation of sintering process and sinter quality were decided by operators according to their experiences .

The traditional digital TV image processing[1,2] uses physical optics method to describe the geometrical shape and the surface roughness of the bed zone . It stresses the appearance of the image . Its features almost use the ready-made statistics[3] for being recognized .

In this paper , we have described the variations of the sectional heat distribution and definited the statistics for image features which could reflect the variation of sintering process. To make a distinction between the digital TV image feature extraction and this feature extraction , the method that called Extraction Features Based on Mechanism is presented.

1 The Primary Feature Extraction

Supposing SISME has an $m \times n$ row , the element of the row is the average

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value measured from units which are divided into equal parts.. For each unit , there is the same volume , density and specific heat capacity. The accumulated heat ratio of line i ($i=1, 2, \cdots, m$), and column j ($j=1,2, \cdots, n$) unit could be calculated by

$$p_{ij}=t_{ij}/\sum_{i=1}^{m}\sum_{j=1}^{n}t_{ij} \tag{1}$$

1.1 Primary feature about combustion

In sintering process , the burning zone contains two variations : the first is the burning space area, which is a geometrical property of burning zone; the second is the fierceness of the reactions, which is the heat accumulation of burning. So we can definite the following statistic as the SISME feature to describe the burning zone.

Definition 1. SISME heat inertia

$$I_h=\sum_{i=1}^{m}\sum_{j=1}^{n}i^2p_{ij} \tag{2}$$

where p_{ij} is the accumulated heat ratio ; i is the line number of the row. i increases gradually in the bed height direction from up to down, and the value of i is greater at the lower level of the row . So if the width of the burning zone or the quantity of accumulated heat in the zone has a small variation , I_h will change greatly , i.e. I_h is sensitive to burning zone .

1.2 Primary feature about the effect of heat convention

The heat convection depends on the gas flow in the bed . If heat convection is good , that means the gas flow is quick , a greater quantity of heat from bed solid is carried downwards, and the difference of temperature value between the higher level and the lower level of the section increases. Otherwise , the difference between them is decreased. In consideration of these , we adopt the following statistic to describe the effect of heat convection .

Definition 2. SISME heat distribution entropy along the height direction of the bed is

$$E_n=-\sum_{i=1}^{m}p_{i\cdot}\lg[p_{i\cdot}] \tag{3}$$

where $p_{i\cdot}$ is the ratio of edge distribution along the bed height direction, which is

$$p_{i\cdot}=\sum_{j=1}^{m}p_{ij} \tag{4}$$

the greater the difference of heat distribution is, the smaller the E_n will be.

1.3 Primary feature about the fuel ratio

Sintering process is a process of excessive oxygen reaction . Keeping the other sintering conditions constant, the variation of sinter mix composition will be the first factor affecting the quantity of accumulated heat in the section. From the heat balance of sintering process, the heat incomes come from fuel combustion, ignition, oxidization of magnetite ore, and other reactions . It is indicated that the fuel combustion heat constitutes 80% among them[4]. Consequently, the variation of fuel ratio is the main and crucial factor which affects the variation of the mean value of accumulated heat of the section .

Definition 3. The heat accumulation mean of the section is

$$M_a=\sum_{i=1}^{m}\sum_{j=1}^{n} t_{ij}\, p_{ij} \tag{5}$$

1.4 Primary features about the abnormality of gas flow and edge gas

When gas flow of the bed distributes in serious heterogeneity, the peak of the heat pattern will prefer moving to the area of the lowest resistance to bypassing the area of higher resistance. Then p_{ij} varies not only along the bed height direction (i) but also along the width direction (j) , which is

$$p_{ij}=f(i.j) \tag{6}$$

therefore , if gas flow distributes uniformly , i is incorrelative with j ; or i is correlative with j .

Definition 4. The correlation of the gas flow between height direction (i) and width direction (j) is

$$C_0=(E(i\cdot j)-E(i)\cdot E(j))/(D(i)\cdot D(j))^{1/2} \tag{7}$$

where $E(i)$, $E(j)$, $E(i\cdot j)$ are the expectations of i, j and $i\cdot j$ respectively, and $D(i)$, $D(j)$ are the variances about i and j . If there is an obvious movement of the peak of the heat pattern along the width direction , the statistic described above is more effective, otherwise , the following statistic is needed .

Definition 5. The symmetry about SISME

$$S_y=\sum_{i=1}^{m}\sum_{j=1}^{n}(p_{ij}-p_{i(n-j+l)})^2 \tag{8}$$

where l is a middle number , if SISME is symmetry , the difference between the two terms in parentheses is smaller , the value of S_y is also smaller; otherwise , the value is higher .

Because of the influence of the edge gas at two sides of the pallet , some outside gas will join into the gas flow in the bed and make the movement speed of the peak of the heat pattern quick at two sides of the pallet , that will change the kurtosis of SISME .

Definition 6. The kurtosis about SISME

$$k_u=\sum_{i=1}^{m}\sum_{j=1}^{n}(1-\sqrt{(j-1)^2}\ )p_{ij} \tag{9}$$

At the edge of the pallet , the value of the parentheses term in equation(15) is bigger , and a little change of p_{ij} will make K_u change greatly. Hence K_u is sensitive to the change of P_{ij} at the edge of the pallet .

1.5 Primary feature about the bed stucture

Because the sintering process is progressing continuously, the change range of p_{ij} is very small at the upper section. But at the lower section , the change range is big. So we adopt the following statistic to describe heterogeneity of the bed structure .

Definition 7. The relative difference of SISME

$$R_d = \sum_{i=1}^{m} \{ (\sum_{j=1}^{n} \sqrt{(p_{i\cdot}/n - p_{ij})^2}) / p_{i\cdot} \} \tag{10}$$

Among which $p_{i\cdot}$ is the ratio of edge distribution along the bed height direction. The difference of the absolute sum of the heat distribution ratio between the lines is much big . Nevertheless, this does not mean that the variation of bed structure is also much big . So we change the absolute sum of difference to the relative sum , and collect all the relative sum, get the R_d .

The uniformity of the bed structure along the width direction decides the uniformity of heat convection and all the reactions along the width direction . So we definite a statistic to describe the uniformity of the bed structure along the width direction here .

Definition 8. The bed width uniformity

$$W_u = -\sum_{j=1}^{n} [(\sum_{i=1}^{m} p_{ij}/p_{i\cdot}) \lg (\sum_{i=1}^{m} p_{ij}/p_{i\cdot})] \tag{11}$$

where $p_{ij}/p_{i\cdot}$ is the relative change of p_{ij} .

Make the above statistic vary as [0,1] , then obtain the 8 dimension primary feature vectors (I_h M_b E_n C_o S_y K_u R_d W_u) .

2 Secondary Feature Extraction

Although the primary features are defined on the basis of the variation of sintering process, they can not independently describe the variation completely and accurately, and they have a great correlation with each other. So it is necessary to alternate the primary features to the secondary ones incorrelated to each other.

Suppose the primary feature of SISME sample is

$$X = \begin{bmatrix} x_1 \\ x_2 \\ \cdots \\ x_n \end{bmatrix} \tag{12}$$

and its covariance matrix is $\boldsymbol{C}$. Suppose the eigenvalues of covariance matrix $\boldsymbol{C}$ are λ_1, $\lambda_2, \cdots, \lambda_n$; eigenvectors are $\boldsymbol{U}_1, \boldsymbol{U}_2, \cdots, \boldsymbol{U}_n$. Each λ_i is a datum, $\boldsymbol{U}_i$ is a column vector of $\boldsymbol{U}$, in which $\boldsymbol{U}_i = (u_{i1}, u_{i2}, \cdots, u_{in})^{\mathrm{T}}$, u_{ij} is a constant datum, the relation between them is

$$\boldsymbol{C}\boldsymbol{U}_i = \lambda_i \boldsymbol{U}_i \quad i=1, 2, \cdots, n \tag{13}$$

From the above equation:

$$|\lambda_i \boldsymbol{I} - \boldsymbol{C}| = 0 \qquad i=1, 2, \cdots, 8) \tag{14}$$

Solve the equation (14), get all 8 eigenvalues, and

$$\lambda_1 \geqslant \lambda_2 \geqslant \cdots \geqslant \lambda_8$$

Substitute the value of the eigenvalue for λ_i in equation (13), then get 8 nonzero eigenvectors as in table 1.

Table 1 The eigenvalues and eigenvector of the covariance matrix C

U_i	I_h	M_a	E_n	C_o	S_y	K_u	R_d	W_u	λ_i
U_1	0.563 5	−0.212 0	−0.517 2	−0.401 3	−0.435 9	0.103 8	0.032 8	0.084 9	0.185 5
U_2	0.075 7	−0.322 7	−0.187 1	0.385 5	0.120 5	0.316 5	0.497 2	−0.587 0	0.092 2
U_3	−0.155 8	−0.188 9	0.236 6	−0.738 8	0.383 0	0.414 9	0.117 4	−0.075 1	0.045 6
U_4	0.048 2	−0.860 5	0.159 6	0.080 6	0.128 1	−343 2	−0.292 2	0.075 2	0.033 2
U_5	0.287 0	−0.090 1	0.259 7	0.251 5	0.110 3	0.268 7	0.439 0	0.708 3	0.010 2
U_6	0.068 4	−0.044 1	0.137 4	0.251 8	−0.169 8	0.703 3	−0.622 0	−0.028 0	0.004 3
U_7	−0.189 8	−0.001 2	−0.710 0	0.106 0	0.566 7	0.103 4	−0.185 5	0.2870	0.001 9
U_8	0.726 0	0.254 3	0.159 8	0.011 9	0.519 9	−0.1473	−0.196 2	−228 1	0.001 2

Suppose the secondary features are expressed as follows

$$\boldsymbol{Y} = \boldsymbol{U}^{\mathrm{T}} \boldsymbol{X} \tag{15}$$

it can be demonstrated that λ_i is the covariance of the secondary feature $\boldsymbol{Y}_k$, and λ_i could reflect the quantity of information in the secondary feature. The bigger λ_i is, the larger the quantity of information in the secondary feature will be. When

$$r = (\lambda_1 + \lambda_2 + \cdots + \lambda_m)/(\lambda_1 + \lambda_2 + \cdots + \lambda_n) \tag{16}$$

($n = 8$, $m < n$) is big enough, we can choose m terms of $\boldsymbol{U}_i$ which is corresponded to λ_i in front of equation (23) to calculate the secondary feature. From table 1, when $m = 4$, r is 95.3%. Therefore it is reasonable to use the following equations to calculate the secondary features

$$y_k = \boldsymbol{U}_k x \qquad k=1, 2, 3, 4 \tag{17}$$

In order to normalize the secondary features.

$$\boldsymbol{F}_k = \alpha_k y_k + \beta_k \tag{18}$$

ir which α_k, β_k are the normalization constant, their value are determined according to the variation of y_k.

3 Analysis of the Classification Effect of the Secondary Feature

Choose some SISME samples and extract their secondary features as in table 2 . In the lights of actually measured FeO content in sinter which was sampled correspondingly to the SISME sampling , we have classified SISME samples into two classes . Take F_1, F_2, F_3, F_4 as coordinate axes, choose two arbitrarily among them and draw the plane diagram as shown in Fig.1 . From Fig.1 we have noticed that the secondary features have a good classification effect on the sinter quality[5].

Table 2 Classified sample matrix (first class)

Sample	C_{FeO}/%	F_1	F_2	F_3	F_4
1	6.40	0.683 0	0.920 2	0.792 9	0.953 5
2	7.40	0.295 7	0.650 5	0.935 5	0.687 2
3	7.80	0.351 1	0.487 9	0.797 5	0.726 7
4	8.70	0.495 1	0.490 6	0.702 0	0.612 1
5	9.00	0.591 0	0.943 7	0.496 8	0.482 5
6	9.30	0.535 3	0.532 1	0.613 3	0.498 9
7	10.35	0.154 4	0.277 4	0.671 4	0.386 0
8	10.40	0.309 7	0.200 2	0.634 1	0.354 6
9	10.60	0.319 4	0.284 3	0.579 2	0.371 5
10	11.10	0.184 3	0.507 7	0.488 5	0.436 1
11	11.15	0.398 9	0.270 7	0.534 3	0.301 4
12	11.30	0.281 9	0.393 7	0.209 2	0.527 0

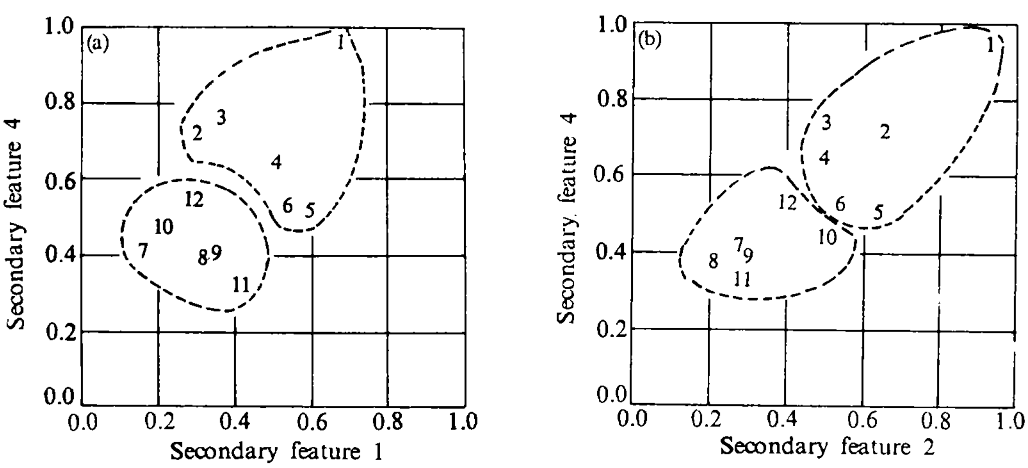

Fig. 1 The Plots ichnographies of samples

4 Conclusions

In this paper, we extracted the primary feature and the secondary features from SISME, analyzed the function of secondary feature, especially established the method of Extraction Features Based on Mechanism. By using the secondary features to classify some SISME samples , we have found that the secondary features have a good classification effect . In addition, this research work will lay down a foundation for the further study on an analysis system about diagnosing sintering process and a recognition system about sinter quality index .

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烧结机尾断面图象的特征提取及其分类

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摘要、本文通过对烧结过程机理的分析，提取了机尾断面图象的一次特征；同时为了使机尾断面图象特征能全面准确地描述烧结过程的变化，本文还在图象一次特征的基础上利用数学变换进行了二次特征的提取。根据对烧结现场一些图象样本提取图象特征表明，利用该方法所提取的图象特征对烧结矿质量有着很好的分类效果．

关键词、烧结，图象处理，模式识别

中图分类号、TF046.4, TP391.41