Research on Real-Time Prediction of Quality of the Slag Overflowing From Furnace Door Based On Image Processing

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Abstract. As an important substance (slag) with the absorption capacity to the harmful elemental phosphorus, saturated slag demanded discharging for both the requirement of the generation of foaming slag in the furnace and slag replacement to strengthen the effect of dephosphorization. This paper reviewed during the electric arc furnace (EAF) steelmaking process for real-time quality of the slag overflowing from furnace door based on image processing. Existing methods, due to high temperature and the on-site production environment, were not considered to weigh real-time spilled slag and the total mass. The real-time composition and quality of the slag in the furnace, which affected the steelmaking process and the quality of products, were significantly influenced by addition of various metallurgical raw materials such as ladle, scrap and lime. The real-time oxidation products and additives could be calculated through the PLC data in the furnace to learn the composition and quality of the slag but it suffered the amount of slag continuously decreasing, due to real-time slag overflowing from the door whose composition was consistent with ingredient in the furnace at that time. The image processing slag from the door serves as a calculating means for the area of the big and small slag areas by the three primary colors of the light and the adjusted pixel channel value. Based on the comprehensive analysis of the situation of the slag from the door, the area of the big and small slag areas were analyzed and extracted to explore the relationship between the area and mass. And the accuracy of calculating the real-time slag was characterized by calculating the volatility of the total mass of the slag from the door counted by each heat. The relationship was verified to calculate the mass of that accuracy was up to 90.48%, which provided a scientific method for predicting the quality of real-time spilled door slag and a scientific basis for predicting in real time the composition and quality of slag in the furnace.

1. Introduction
The slag overflowed beyond the furnace door could be called slag from the door during the process of electric arc furnace (EAF) steelmaking. As the absorbent of harmful elemental phosphorus vital for the quality of products[1], the real-time composition and quality of slag in the furnace should be accurately calculated[2], but it suffered the amount of slag continuously decreasing, due to real-time slag overflowing from the door for both the requirement of the generation of foaming slag in the furnace and slag replacement to strengthen the effect of dephosphorization[3,4], whose composition was consistent with ingredient in the furnace at that time. Therefore, real-time quality of slag overflowing from the door could be counted by image processing. Image processing techniques have been used extensively in various applications, including in the object recognition, in fluid mechanics, in measuring the amount and distribution and in the estimate of the thickness of substance [5-8].

Since the generated slag mainly attributed to oxidation reaction of the molten steel element in the furnace based on the value of Gibbs free energy, and real-time addition of accessories, such as lime
and oxygen, were also close associations with the slag in the furnace [9]. The composition and quality of the slag in the furnace in real time could be counted theoretical calculation through computer program.

The slag had a great influence on the steelmaking process and the quality of the steelmaking products [10]. However, at present in the industrial production, the workers in the plant still used their eyes and experience to observe and judge the real-time situation and mass of over-flowed slag from the slag door due to no statistic and calculation about the over-flowed slag in EAF steelmaking process [11]. Furthermore, it was difficult to weigh the over-flowed slag in a real time because of many factors such as the high slag temperature 1400°C − 1500°C [12]. Thus, image processing method has been used in analyzing, processing and calculating real-time slag from the door to contribute to slag prediction in the furnace.

In this study, the over-flowed slag from the slag door in an EAF smelting process was recorded by a video camera and the area of slag was analyzed and calculated based on image processing method. The real-time mass and the total mass of the over-flowed slag were also calculated. Besides, the prediction method was analyzed by the relationship of area and mass of slag, which showed that the accuracy reflected by volatility of total slag was high up to 90.48%. This study has a great practical significance for judging the furnace situation, adding slag, and effectively controlling the quality of steelmaking products.

2. Experimental Methods

2.1. Camera and Software Versions

An image processing model independently developed worked as the analysis and calculation of the slag from the door, such as the area, the quality and the total mass. The model was wrote by the programming language C# on the platform of Visual Studio 2010, to which leading EmguCv open source visual library model or function had a role in programming. Through the "MV-GE231GC-T+MV-LD-50-3M-A" industrial camera, of which parameters were shown in the table1, the video of the slag overflowing from the furnace door was captured in real time, the camera parameters were as shown in the table1. At the same time the real-time overflowing slag image was analyzed, depending on the image processing model to calculate the area and quality of the real-time slag from the door.

| Camera parameters | Feature |
|-------------------|---------|
| resolution@frame rate | 1920ution@frame r |
| pixel bit depth | 12bit |
| field angle | 10.5d angle"h |
| frame buffer | 32M Bytes |
| programming language | C/C++/C#/VB.NET/Delphi, BCB/Python |

2.2. Video Image Acquisition

The video images of slag overflowing from the door could be captured by the industrial camera which was set at a position 20 meters away from the slag. A good shooting angle and taking the upper part of the overflow channel were the mostly commonly employed approach for high-definition images during the shooting. Because images photographed by the camera may involve the slag that had fallen to the ground. The falling time of slag from the door was arranged to be less than the image processing time to avoid repeating calculation of image of the slag, and then the exposure and the focal length should be adjusted, forming dark and clear images to make the difference between the background and the target to be tested. And the video taken every time was saved for subsequent analysis, processing
and calculation, of which the schematic diagram captured and the effect diagram were respectively shown in the Figure1 and Figure 2.

![Figure 1. Schematic diagram of capturing video images](image1)

![Figure 2. The effect diagram of capturing](image2)

3. Analysis of Real-Time Overflowing Slag Image

When the image processing program was mixed with the video image of slag from the door, each frame of image shot by the industrial camera was written into the program in which the color characteristics continuously was extracted in real time. No pre-processing was performed in processing the images of the slag from door, whereas the gray value of the slag from the door was largely different from the value of the surrounding light and shadow (background). After adjusting the focal length and exposure of the camera, the three primary color values (240,240,150) of the light in the program was set and used for distinguishing the white color characteristics of the big slag from door of which values were above (240,240,150). The characteristics would remain for the percentage of slag area counted by means of statistical pixel. The percentage W represented slag area accounted for the entire image area percentage, could also be expressed as the ratio of the area of the slag overflowing from door to the background area of the shot.

3.1. The Analysis of Quality Calculation

The image processing model was suitable for processing and analyzing slag from the door in real time due to its non-contact. For calculating the quality of the slag from the door in real time, the process mainly was consisted of the following steps, namely the calculation of the real-time spilled slag area S and fitting calculations for the relationship between the area and mass.

3.2. Calculation of Real-Time Slag Area

The background area was based on the situation fixed at the time of shooting, which was counted by the camera's field angle(\(\angle AOB = 10.5^\circ\)) and the distance L (20 meters) from the camera to the slag overflowing from the door measured by the infrared range finder. The site layout diagram was shown in the Figure3 and the formulas of calculating the background area and the area of the slag overflowing from the door in real time were shown in formula 1 and formula 2.

![Figure 3. The site layout diagram of shooting](image3)
3.3. Calculation of Real-Time Slag Quality

The electric arc furnace placed on the roadway, the industrial camera should be separated from the slag from the door during the shooting, as shown in Figure 1. Because of the information of the slag from the door captured by the camera, the thickness parameter of the slag was obtained uneasily. Further, as a result of fixed shape of the furnace door and almost the same angle of the electric arc furnace tilting out when the steel was poured, using area density would be facilitated for the quality of slag from the door in real time due to relatively stable thickness of the slag, despite possible deviation existed in calculation. In the process of image processing real-time slag overflowing from the door, the main flow of the slag, with a small part of the slag splashing out, by the RGB channel coefficients above (240,240,150) of the three primary colors in the image processing model could be identified, then calculating the area of the big slag. The calculation formula which counted the mass of the real-time slag overflowing from the door and the total mass, involving parameter $K_1$ which was defined as the area density, was characterized in proportion to the big slag area $S_1, S_2, ..., S_n$ and as listed below. $K_1$ was determined by the volatility of the total slag amount which represented this formula in line with the relationship between slag area and quality, then calculating the mass of the real-time overflow and the total mass. In the experiment, real-time shooting and image processing were carried out on the five furnaces slag overflowing from the door, and the image processing interface was shown in the Figure 4, on which the real-time slag area percentage and the quality of the slag slag were calculated in real time.

\[ M = K_1 \times S_{\text{big}} \]  

\[ M_{\text{Total}} = \sum_{\text{pictures}} K_1 \times S_{\text{big}} = K_1 \times S_1 + K_1 \times S_2 + K_1 \times S_3 + K_1 \times S_4 + ... + K_1 \times S_n \]  

**Figure 4.** The image processing interface
4. Image Processing Real Time Slag and Area and Quality Correction Relationship

The first method of calculation of the quality of the real time slag from the door used area density $K_1$ for the area and quality of slag. From the accuracy of calculation of the slag quality, studying the relationship between the area and the thickness appears more accurate for counting the quality, provided the slag area was related to the slag thickness in real time.

During the slag from the door in real time processed and calculated by the image processing model it was found the thickness on both sides was relatively thinner than in the middle, defined as uneven distribution of the slag, which should be properly processed and calculated. It was a relatively good view for treatment of the slag would appear as a cuboid by segmentation. Meanwhile, imagine that the thickness and area of countless small pieces that divide large slag are closely related. The slag density is relatively stable at $2.3 \times 10^3 \text{Kg/m}^3$, and has viscosity whose fluctuation is not large at a high temperature of $1400 \degree C - 1500 \degree C$. Due to the slag viscosity, the larger the overflow area was, the thicker the thickness was. Therefore, the real-time spillage of slag was calculated from the relationship between real-time area and thickness and using the index $m$ of slag area served as a discussion of the relationship. Calculating the quality of the slag overflowing from the door in real time and the total amount of slag were shown in the following formula 5 and formula 6.

$$M = K_1 \times S_{big} \times D = K_1 \times S_{big} \times K \times S_{big}^m = K_2 \times S_{big}^{m+1} \quad (5)$$

$$M_{total} = \sum_{picture=1}^{pictures} K_2 \times S_{big}^{m+1} = K_2 \times S_1^{m+1} + K_2 \times S_2^{m+1} + \ldots + K_2 \times S_{n}^{m+1}$$

$$\sum_{picture=1}^{pictures}$$

Due to the actual situation that the thickness of the slag from the door was smaller than the height and width of the slag, the value of index $m$ in above formulas was explored at less than 0.5. The formulas were found by a certain value $m$, and then were applied to calculate the quality of real time slag from the door and the total mass. Therefore, the index value $m$ of which range was from 0 to 0.5 was set and with an interval of 0.05 was probed by the metrics of coefficient of variation. The coefficient of variation, of which formula equaled the quotient of the standard deviation and the mean, was used to evaluate the curve volatility of the total mass of each furnace slag from the door calculated. The smaller the coefficient of variation was, the smaller the volatility was. The coefficient of variation was shown in the Figure 5. When the curve fluctuation was the smallest, the value $m$ in the calculation formula was determined, then calculating coefficient $K_2$ and the mass of and real-time slag overflowing from the door.

![Figure 5. The coefficient of variation of the total quality](image)

In the above, exclusively the quality of the big slag from the door on the mainstream of overflow was discussed, thus determining best index value $m$. However, the total mass of slag of multiple furnaces calculated still had large fluctuation. The fluctuation could be related to the amount of dispersion and overflow of the small slag, which was worth studying.
Since the small slag overflowing from the door with different sizes were similar to that of the big slag, the small slag door slag appears in the yellow or light yellow area, compared with the linear red area which was considered to be not included in the total slag amount. The quality of the small slag was believed to be omitted; the calculation of the total amount of slag from the door would cause an error which the total mass of per furnace fluctuates greatly. Moreover, the area of the small slag and the big slag from the door could not be simply added and then participated in the calculation as the result of the thickness difference. More errors could be involved, provided the total mass of the slag was calculated by this method. It was indicated that the thickness of the big slag from the door was relatively stable during the overflow of the slag due to fixed furnace door. Various small block areas was converted into a big area, which was expected that the thickness of the big slag remained approximately unchanged. And the big slag overflowing from the door appeared white, of which the edge was covered with a layer of golden yellow flakes and the outermost layer was the red area caused by exposure, in addition the small slag overflowing from the door was yellow and the edge was red. The distribution of these areas was shown in the Figure 6.

By detecting the real-time video image, the RGB values of the yellow, gold and red regions extracted by the suction device were randomly collected in these corresponding regions. But it was found since the small slag of the furnace door showed bright yellow on occasions; the golden and yellow areas in the image were difficult to separate by the RGB values. RGB values of fifty places, which made color areas distinction more representative, were randomly obtained for light yellow area where the relatively small furnace door slag was located, as the golden yellow area and the red area could be done. Since the R values of the three colors differ slightly and were above 240, only the values of G and B were statistically analyzed, which were collected is shown in the Figure 7.
Through the statistics, the relatively lighter yellow areas and the golden areas are larger than the value \( G = 150 \) in the set RGB value, thus distinguishing from the red area due to exposure. And randomly 10 sets of RGB values were selected from the big golden area, the red area adjacent to the golden area, the small yellow area and the red area adjacent to the yellow area, as shown in the Table 2, it was shown that the value \( G \) which was adjusted to 150 could cause the yellow area and the golden area were separated from the red area.

### Table 2. the RGB values of representational color regions

| yellow area RGB value | near the yellow area red area RGB value | golden area RGB value | near the golden area red area RGB value |
|-----------------------|----------------------------------------|-----------------------|----------------------------------------|
| (253,236,14)          | (255,117,0)                            | (254,254,253)         | (255,142,0)                            |
| (253,182,0)           | (255,107,26)                           | (254,253,255)         | (255,147,0)                            |
| (255,197,0)           | (255,106,2)                            | (255,255,253)         | (255,140,20)                           |
| (255,204,8)           | (255,138,0)                            | (254,254,253)         | (255,129,25)                           |
| (249,237,2)           | (255,142,27)                           | (255,251,211)         | (255,139,20)                           |
| (253,236,0)           | (253,134,23)                           | (253,254,252)         | (255,39,25)                            |
| (252,231,0)           | (253,134,26)                           | (255,254,253)         | (255,146,10)                           |
| (255,230,1)           | (255,131,0)                            | (254,254,253)         | (255,127,17)                           |
| (255,202,0)           | (248,106,41)                           | (254,254,253)         | (254,131,21)                           |
| (255,245,25)          | (255,130,35)                           | (255,255,244)         | (247,142,22)                           |

Real-time images were dealt with by setting RGB values which equaled (240, 150, 0) in the image processing model, which led to the separation the red area from all the areas. But at the RGB values, it is accompanied by calculation of the big area of slag from the door. Therefore, program is highly tuneable and capable of producing two different calculation channels of the small and big slag in the image processing model, double-threading was performed to process the video image of the real-time slag from the door. The area of the small slag from the door equaled the area counted by RGB values which equaled (240, 150, 0) minus the area counted by RGB values which equaled (240, 240, 150) to be on behalf of the white area of big slag, thereby calculating the area of the yellow and golden areas. And these areas were considered to the small blocks and then were processed when calculating the slag quality.

The video of the five furnaces slag overflowing from the door recorded in real time was processed and retested though image processing mold optimized by adjusting the value of RGB. These formulas, calculating the mass and total amount of real-time overflow furnace door slag were shown in formula 7 and formula 8, \( S_{\text{small},A} \ldots S_{\text{small},X} \) and \( S_{\text{big},1} \ldots S_{\text{big},n} \) respectively represented the area of the small slag from the door and the area of big slag on the main stream in each image.

\[
S_{\text{small} \rightarrow \text{big}} = \frac{S_{\text{small}}}{S_{\text{big}}} \times S_{\text{small}} \tag{7}
\]

\[
M = K_2 + \left( \frac{S_{\text{small},A}}{S_{\text{big},3}} + \ldots + \frac{S_{\text{small},X}}{S_{\text{big},1}} \right) + K_1 \times S_{\text{big}}^{\alpha} = K_2 + \frac{S_{\text{small},A}}{S_{\text{big},3}} + \ldots + \left( \frac{S_{\text{small},X}}{S_{\text{big},1}} \right)^2 \tag{8}
\]

According to the formula 10, the smaller pieces have a very little influence on calculation of the quality of the real-time slag from the door quality and the total slag mass, sometimes even the non-furnace door slag area was calculated to increase the deviations. According to the close relationship between the RGB values of the small slag piece with its size, that is, the smaller slag door slag had a larger relative surface area due to its faster heat dissipation. Moreover, it was found the color of the smaller areas was more yellow than the bigger one. Therefore, the influence of small slag pieces on
the calculations could be controlled by adjusting the image recognition RGB value (240, 200, 0). The investigation and study were carried out at intervals of 0.05 respectively. The index \( m \) in the range of 0 to 0.5 was selected at the interval of 0.05, calculating corresponding quality of real-time slag overflowing from the door and total slag. According to the calculation in the relationship of the mass of the total slag, the slag area relationship values of five furnace test were calculated. Since the index \( m \) was taken at different values, the constant value \( K_3 \) could not affect the volatility of the total slag amount which could be represented by the volatility of area relationship values calculated as shown in the Figure 8. The fluctuation of the total amount of slag, which indirectly indicated the stability of calculating the quality of real-time spilled slag, was characterized by calculating the coefficient of variation, as shown in the following Figure 9.

![Figure 8. Slag area relationship values](image1)

![Figure 9. The coefficient of variation of the total mass](image2)

The total mass of slag that overflowed from the furnace door during the steelmaking process did not be weighed, but it could be calculated according to the principle of mass balance. The composition of slag in the furnace and mass of overflowing slag also could be calculated. The mass of overflowed slag per furnace was about 9 tons which was theoretically calculated from the composition and mass of the added ladle slag in the initial smelting, the amount of added lime during the smelting process, and the mass of formed SiO\(_2\), MnO, P\(_2\)O\(_5\), FeO and Fe\(_2\)O\(_3\) by the oxidation reaction in the furnace, of which chemical reaction formulas were shown in formulas from 11 to 15. The calculated total masses of overflowing slags were 7539.9351kg and 8746.4165kg, and the calculation accuracy was reached 90.48%.

\[
\begin{align*}
\text{Si} + \text{O}_2 & = \text{SiO}_2 \\
2\text{Mn} + \text{O}_2 & = 2\text{MnO} \\
4\text{P} + 5\text{O}_2 & = 2\text{P}_2\text{O}_5 \\
2\text{Fe} + \text{O}_2 & = 2\text{FeO} \\
4\text{Fe} + 3\text{O}_2 & = 2\text{Fe}_2\text{O}_3
\end{align*}
\]

5. Conclusions
The real-time prediction of over-flowing slag from the slag door during the EAF smelting process was studied based on image processing method. The relationship between the area and mass of real-time overflowing slag was studied to the mass of real-time slag by combining the actual situation and the video image of real-time overflowing slag from slag door was analyzed, processed and calculated. The accuracy of the calculation was verified through calculating the fluctuation of the total mass of the overflow slag. It meant that slag from the door in the mainstream image and the relatively big small-piece slag could be calculated in a real time through the developed image processing model. At last, it was verified that the accuracy of mass prediction was up to 90.48%. Our study provides a scientific method for predicting the mass of real-time spilled slag and a scientific basis for predicting the
composition and mass of slag in the furnace in real time. Following the observations presented in this study it can be concluded that:

1. Double-threading was performed to process the video image of the real-time slag from the door, defined as the first threading of the image recognition RGB value (240, 240, 150) and the second threading of the image recognition RGB value (240, 200, 0).

2. The results indicated that the relationship between the areas of the real-time large and small slag from the door and mass was shown in formula (9).

\[
M = 1.014 \times 10^{-4} \times S_{\text{big}}^{-1.15} \left(1 + \left(\frac{S_{\text{small}}}{S_{\text{big}}}\right)^2\right)
\]  

(9)

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7. References
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