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Integrated prediction model of bauxite concentrate grade based on distributed machine vision

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ABSTRACT

Concentrate grade of bauxite flotation is an important technology indicator, which has a direct effect on aluminum quality. Considering the unity, locality and inaccuracy of existing prediction methods of concentrate grade based on machine vision, a distributed machine vision system of bauxite flotation process is built in this paper, from which an integrated prediction model of concentrate grade is presented. At first, we use experimental methods to analyse image data from different flotation stages, as well as comment on the relationship between its global trends and local trends. Then taking advantage of the multiple kernels least squares support vector machine and wavelet extreme learning machine, models for prediction of concentrate grade and its residual compensation are established respectively to predict the concentrate grade through integration. Finally, validation and industrial applications show that the integrated prediction model based on distributed machine vision has a good generalization capability, which can achieve a good prediction accuracy of concentrate grade, with a relative error of less than 6%, thus laying a foundation for optimal control based on mineral grade in flotation process.

1. Introduction

Concentrate grade and recovery are the primary objectives in diasporic-bauxite flotation process. The grade can be obtained online from an X-ray fluorescence analyser, and the recovery is computed from grade measurements. However, the online measurement is very expensive, and the instrumention is often inaccurate and more subject to damage because of high content of pulp concentration of bauxite, so the grade measurement mainly depends on laboratory analysis. However, off-line analysis is long and tedious, with delay time ranging from 2 to 4 h, making it difficult to offer a practical guide to industrial operations (Xu et al., 2012; Zhou et al., 2009). Process operators normally predict the concentrate grade based on the froth appearance and then adjust the operating parameters such as dosage and aeration (Morar et al., 2012; Nakhaei et al., 2012). This manual observation is characterized by subjectivity and uncertainty, which might easily lead to excessive reagent dosages and severe process fluctuations. Therefore, it is very important to study the prediction of concentrate grade, for the purpose of stabilization and optimization of flotation process as well as reagent consumption.

Several authors have attempted to predict the mineral grade based on froth characteristics, such as Hargrave and Hall (1997), Hätönen et al. (1999) and Bonifazi et al. (2000), studied the relationships between froth color combined with other characteristic parameters and concentrate grade. However, these authors have not taken the illumination into consideration, which might easily affect the obtained froth characteristics and grade prediction. Therefore, Heinrich (2003) described the effects of illumination on color space that would solve this problem. In addition, they show that froth colors of different minerals vary widely and the relationship between chalcopyrite and gangue mineral is quite complicated, and requires additional parameters. Except for the single color parameter, additional research focusing on froth color, froth speed, stability and concentrate grade was conducted. Hyotyniemi et al. (2000) suggested that a froth stability measurement provided a linear correction with zinc concentration in the rougher tails. Morar et al. (2005), Hätönen et al. (1999) and Hyotyniemi et al. (2000) used the froth color, froth speed and stability to predict the mineral grade, which resulted in higher prediction accuracy, and they all agreed that more accurate predictions could be achieved when these parameters (froth speed and stability) were used in conjunction with color.

However, these vision-based prediction models aimed at a single flotation cell. They cannot fully characterize the flotation froth of whole flotation circuit, especially for the diasporic-bauxite flotation (Zhongzhou, China), due to its long process and large time delay. This makes these methods mentioned above have substantial limitations in the grade analysis, with difficulties in adequately

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reflecting the concentrate grade, resulting in a poor prediction accuracy of the models. Moreover, in terms of fluctuations in working conditions, it is hard to accurately track the variations in concentrate grade, so certain errors between actual values and predictive values seem to be unavoidable.

Based on the previous analysis, in order to improve the prediction accuracy of concentrate grade, a flotation system based on distributed machine vision is proposed in this paper, from which an integrated prediction model is presented. Firstly, the diasporic-bauxite flotation process is presented in Section 2. Then, the global and local trends of froth characteristics of different flotation stages will be studied in Section 3, followed by an integrated prediction model of concentrate in Section 4, in order to accomplish the grade prediction and error compensation, respectively. Finally Section 5 explains the application of proposed models in a bauxite flotation plant to validate the prediction accuracy, which lays a foundation for the process modeling, coordination and optimization of overall flotation process, from feed ore to concentrate grade and tailings grade.

2. General description of bauxite flotation process

This paper concentrates on the diasporic-bauxite flotation circuit in Zhongzhou, China. It uses the positive flotation technology, namely achieving the concentrate from the flotation froth while the tailings are obtained from the underflow. The diasporic-bauxite in China is characterized by a high content of Al_2O_3 and SiO_2, and a low ratio of Al_2O_3 and SiO_2 (Al_2O_3/SiO_2, A/S, usually between 5 and 6). The bauxite flotation circuit is a long-time and complex separation process, consisting of the following flotation banks: roughing bank, rough-scavenging bank, clean-scavenging bank, cleaning I bank and cleaning II bank. Each flotation bank is comprised of dozens of flotation cells. This is done to ensure both high concentrate grade in the final product and high overall recovery. A concise diagram of the flotation circuit of the bauxite dressing plant is displayed in Fig. 1.

The mineral processing starts with grinding, where the particle size of the ore is reduced down to powder of micrometer level. Then, the powder is mixed with water and some special reagents, and the resulting slurry is fed to an agitated tank, where the useful mineral particles are selectively coated with hydrophobic chemicals. After this, slurry is fed into roughing cells, where pulp and bubbles are formed by stirring with impellers. Then, bubbles with attached valuable mineral particles will rise and flow out of the roughing cells into cleaning I for the first cleaning, while the underflow slurry goes into the rough-scavenging. After that, froth overflowing from cleaning I flows into cleaning II and forms the final concentrate. Meanwhile, the underflow slurry of cleaning II enters cleaning I, the cleaning I underflow enters the clean-scavenging. Froth overflowing from the rough-scavenging and clean-scavenging, however, returns to roughing and cleaning I respectively for another separation, while their underflows enter into the final tailings.

Concentrate grade is one of the most important indicators of flotation performances, which represents the indices of process productivity and product quality, so flotation plants often regard it as an objective of maximizing economic benefit. However, the current vision-based prediction model researches mainly concentrate on a single flotation cell (usually aimed at roughing cells), which cannot fully characterize the flotation froth of the whole flotation circuit. Therefore, we propose a distributed machine vision system of bauxite flotation process in this paper, where cameras are installed above the first cell of roughing, the last cell of rough-scavenging and the last cell of cleaning II respectively, as shown in Fig. 2. Froth images of different cells can be obtained from this system, followed by analysis of froth characteristics and dynamic modeling of the flotation process.

3. Acquisition and correlation analysis of froth characteristics of multiple flotation cells

3.1. Froth characteristics acquisition of different working procedures

Froth images of different flotation cells obtained by using the distributed machine vision platform are shown in Fig. 3. As can be seen from the obtained froth images, froth in each flotation cell

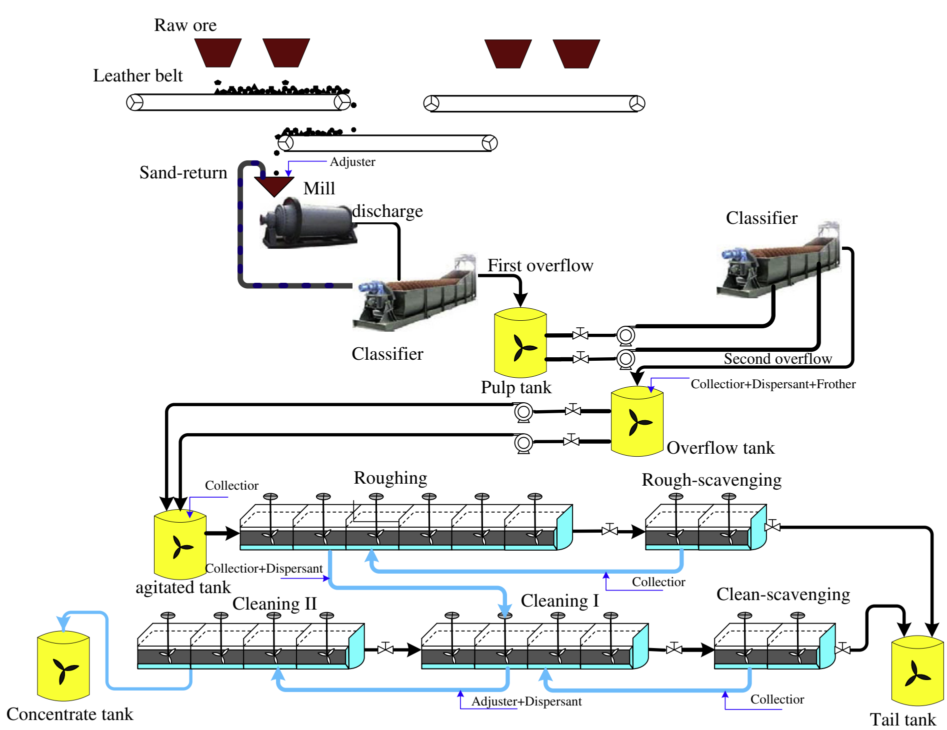

Fig. 1. Flow-diagram of the bauxite flotation circuit.