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Multi-model soft measurement method of the froth layer thickness based on visual features

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ABSTRACT

The flotation froth layer thickness is an important factor for production performance. Influenced by the harsh environment of the production site, the flotation froth layer thickness is difficult to measure accurately. This paper proposes a multi-model soft measurement method of the froth layer thickness based on the visual features. In this method, the froth layer thickness is established by the kernel extreme learning machine (KELM) according to different working conditions. The membership of the current froth image for each of the working conditions is obtained based on the combined similarity coefficient and is used as the combination of weights of multiple sub-models to realize the global soft measurement model. The performance of the soft measurement model is verified by the industry production data. Based on the KELM global model, the root mean square error and the average relative error of predicting the thickness of the froth layer in the experiment are 3.01 and 3.98%, respectively, which show that the model has high prediction accuracy and strong generalization performance. This method provides a new way for froth layer thickness measurement and the basis for controlling flotation process.

1. Introduction

Froth flotation is a process that separates the valuable minerals from the complex ore, based on differences in the hydrophobicity of the constituents [1]. Initially, a large quantity of bubbles is formed, and the mineral particles with high hydrophobicity adhere to the bubbles. The froths will float to the surface, which leads to the formation of a stable froth on top of the flotation cell. Thus, the valuable mineral in the froth layer is scratched from the flotation. In this manner, the valuable mineral can be concentrated. The features of the flotation froth layer's appearance are closely associated with the process index and operational variables of the flotation process [2]. According to different working conditions, the froth layer appearance features will be varied [3]. In the flotation plant, in order to improve economic efficiency and resource utilization, some operational parameters must be adjusted accurately in practice, such as the froth layer thickness, the ventilation quantity and the addition dosage [4]. In addition, in case of a certain amount of ore and addition dosage, it is common to adjust the froth layer thickness to meet the process requirements [5]. However, currently the adjustment of the froth layer thickness mainly depends on the operator's experience combined with the bubble's characteristics. Due to the highly subjective nature of the operator's experience and the lack of uniform standards, it is very difficult to ensure the stable operation of the flotation process [6]. Therefore, further research on the measurement of the froth layer thickness is required. With the development of an innovative method, the thickness could be measured accurately in real-time, which can act as a reference to guide the optimization control of the production process.

Because of the tough conditions in the flotation plant, the status of the froth layer in the flotation plant would suffer from intense changes continuously. In addition, some chemical reagents of high corrosion are added to the flotation cell, making the accurate measurement of the froth thickness difficult to achieve. Currently, researchers from all over the world have performed several studies on this topic [7–9,23,24]. Maldonado [7] proposed that the difference in conductivity between the froth layer and the liquid-level can be used to measure the thickness. However, it can only be realized in a flotation column. Hamilton [8] introduced a new method using gamma rays which are strongly associated with the thickness. Gamma rays not only dependent on power of the ray sources, but also have negative effects on people's health, which makes the method impractical in the plant. He applied sensors to the thickness measurement of froth layer, but the results were unsatisfactory [9]. Most of the previous studies have focused on the measurement of physical characteristics, which can be obtained by the use of certain instruments, to determine the thickness. However, due to the hostile conditions in the flotation plant, the accuracy of such measurements is unsatisfied and it is difficult to maintain the instruments, making it impossible to operate them for a long period. In addition, most of these instruments are expensive, so the capital expenditure is high for these methods.

With the development of image processing and machine vision technology, some supervisory methods based on machine vision have been widely applied in the flotation process control. Sadr-Kazemi and

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Cilliers [10] pointed out that accurate and rapid detection of the bubble size and shape distribution on the surface of flotation froth were strongly associated with flotation performance. Sameer H Morar [11] also illustrated that the measurement of physical machine vision measurements could be able to provide accurate measures of mass recovery rate and concentrate grade across variations in operating conditions. Xu [12] proposed a method of the fault detection for reagent addition in industrial froth flotation process based on machine vision techniques. Supomo [13] found that the Machine Vision system could be practicable to replace the human visual observation and the permanent monitoring and quantitative determination of froth properties could be realized.

However, most of these research results are concentrated with the prediction of flotation performances. In fact, it can be seen that the froth layer thickness is strongly associated with the fusion appearance features from a large quantity of experimental data, so with the appearance features, the froth layer thickness can been precisely predicted [14]. In addition, some techniques have been developed to extract the appearance features in the flotation more accurately, which can provide comprehensive information of the image. For example, Gui [15] proposed a texture feature extraction method based on color co-occurrence matrix (CCM), which can provide much effectiveness an superiority compared with commonly used method based on gray-level co-occurrence matrix (GLCM). However, the flotation process is a complex process with multiple working conditions. As a result, a single model cannot be used to reliably predict the thickness. Therefore, a new method based on multiple model measurements is proposed to address this issue.

In Section 2 the working principle of the flotation cell and the key fusion appearance features of flotation layer thickness are described. Then, the framework of the multiple model soft measurement method is introduced. Some image feature extraction methods are used to extract the appearance features, such as froth layer texture, color, speed and stability in Section 3. Moreover, the features are used to construct the froth appearance feature vector. In Section 4, in terms of a comprehensive similarity coefficient, the current working condition's membership degree of the historical working conditions can be evaluated. In Section 5, based on the froth layer appearance features, froth layer thickness soft measurement local models with respect to different working conditions are constructed using the kernel extreme learning machine. Furthermore, weighted fusion is used to obtain the global model according to the membership degree of the working conditions, and the online real-time measuring of the thickness can be realized using the global model. In Section 6, considering the case of the data from the rough flotation process in a gold-antimony flotation plant, the soft measurement model is found to have high accuracy and strong extension capacity. Finally, conclusions are given.

2. Multi-model soft measurement strategy of the froth layer thickness

Froth flotation is one of the most commonly used mineral separation methods in the mineral processing industry. Froth floatation is used to separate valuable minerals from unwanted materials or other materials based on the differences in wettability of the various mineral particles. The flotation process is performed in a flotation cell, which is a gas–liquid-particle three-phase system; the working principle is shown in Fig. 1. First, the air is aerated into the flotation cell, and bubbles are created with the rotor stirring. Next, the hydrophobic valuable mineral will adhere to the bubble surface and rise to the top of the cell, which results in the formation of the froth layer with mineral enrichment. With the flotation reagents and the driving force from the lower bubbles, the upper bubbles will be constantly rising to the top of the flotation cell, and the concentrate overflow will be carried to the side tank. In contrast, hydrophilic particles primarily remain in the water, which will be discharged with the pulp flow.

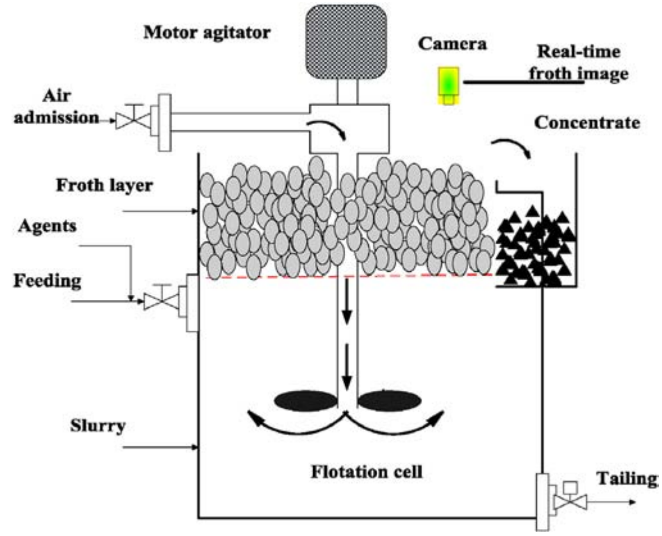

Fig. 1. The principle of the flotation cell.

The froth layer thickness is an important factor related to the flotation performance, which directly affects the concentrate grade and recovery of the flotation process. A large amount of valuable metals is enriched in the froth layer. As a result, the appropriate thickness of the froth layer is conductive to the stability of the mineralized froth and metal enrichment, which would improve the concentrate grade and mineral recovery of the flotation cell. On one hand, if the layer is too thick, then the opportunity of the collision between the mineral particles and bubbles is reduced, leading to insufficient flotation and the decrease of the concentrate grade. On the other hand, if the froth layer is too thin, then the secondary enrichment will be reduced and the concentrate grade will be lowered. In addition, with a thin layer, the transgression phenomenon is prone to occur, as the pulp is easily scratched. In the plant, to increase the concentrate grade, a thicker froth thickness is required in the cleaning process. While seeking a higher recovery and a reduction of the particle residence time in the froth layer, the froth layer should be thin in the scavenging and roughing process, for which the floated mineral would be blown out immediately. Therefore, the study of the process of online real-time froth layer thickness soft measurement is vital for the optimization of the control, stable processing, and energy savings of the froth flotation.

When the froth layer thickness is different, the mutual accumulation external force that the froth surface suffers from in the cell is also different. As a result, the appearance features of the bubble, such as structure and shape, become altered, and the variance can be intuitively reflected via the static and dynamic froth layer appearance features. In addition, some research has found that the texture features, morphological features, color features and dynamic features can describe the froth layer thickness accurately; thus, the froth layer appearance features can be the basis of thickness measurement of the froth layer.

Because the flotation is a production process with long process duration, complex technology, high noise and multivariate characteristics, therefore, using a single soft sensor model is not able to accurately describe the global characteristics of the complex system. The robustness of the single soft sensor model is poor, and the generalization ability of the model is weak. To improve the precision of the soft measurement model, the multiple-model soft measurement method [20] for determining the mineral flotation froth layer thickness is introduced in this paper. The idea of the method can be described in two steps. First, the flotation production process is divided into several typical working conditions, and the local soft sensor model of each working condition is established. Second, the global soft sensor is obtained by weighted fusion of the local models. The advantage of the proposed method is that it can choose the most suitable modeling feature and the appropriate