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A fault prediction method that uses improved case-based reasoning to continuously predict the status of a shaft furnace

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ABSTRACT

For the problem of predicting faults in the status of a shaft furnace, the missed alarm rate and false alarm rate have not been improved significantly by the traditional case-based reasoning (CBR) method. To predict faults more accurately, an improved CBR-based fault prediction method (ICBRP) is proposed in this paper. This ICBRP is composed of a water-filling theory-based weight allocation (WFA) model and a group decision-making-based revision (GDMR) model. According to the optimal allocation mechanism of channel power, a Lagrange function is designed to calculate the weights. Moreover, the credibility of historical results is used to revise the predicted results via the definition of a group utility function. Then, the proposed reasoning strategy can obtain more reasonable weights and take full advantage of comprehensive information from the retrieval results. Finally, the application results indicate that the proposed method is superior to traditional CBR and other methods. This proposed ICBRP significantly reduces the missed alarm rate and the false alarm rate of failure in the furnace status.

1. Introduction

A shaft furnace that roasts hematite ore for mineral processing is a large-scale industrial kiln that is categorized as a type of thermal equipment. One of the important technical processes that a shaft furnace performs is to turn weak-magnetic mineral ore into strong-magnetic ore; this process is known as roasting [4]. Because the furnace conditions of a roasting process are quite complex, there is a substantial number of fault points that could occur in the process. When a fault occurs in the process, it will affect the production process and threaten the safety of the personnel and equipment. Therefore, it is necessary to discover the fault points as early as possible and to conduct the appropriate treatments in a timely manner to avoid fault deterioration and unnecessary economic losses [5]. However, a model of the mechanism of the roasting process is difficult to obtain [31]. Because the shaft furnace roasting process suffers from a variety of disturbances, it is difficult to achieve an accurate prediction by the ordinary fault prediction methods. Therefore, it is crucial to pursue an appropriate approach to predicting the variations in the trends of the shaft furnace status [32].

Since the 1970s, Lu and Saeks have studied fault prediction [18]. A wide array of fault prediction methods has been introduced. These fault prediction methods can be grouped into three categories, namely model-based methods [9], knowledge-based methods [8,22,24,26,28,29] and machine learning methods [3,11,12,17,30,33]. The model-based methods obtain future fault features through the estimation of model parameters [9], while the knowledge-based methods use the knowledge of experts in the field to form rules for fault prediction. The machine learning methods catch future fault features by modeling the complex relationships between the inputs and outputs. However, most of the complex industrial processes

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possess characteristics such as slow time variance, distributions of parameters, nonlinearity and strong coupling, and it is difficult to describe the industrial systems by mathematical models [5]. Therefore, knowledge-based methods and machine learning methods, which do not require the establishment of exact mechanism models, have emerged. The effects of these methods have achieved a certain level of success. However, the knowledge-based methods and the machine learning methods are in general plagued with problems (e.g., the problem of acquiring the rules, the convergence problem of neural networks, and so on). Case-based reasoning (CBR) in artificial intelligence is a new method that seeks to improve the problem-solving and learning skills of machines. The process conducted by CBR can be described as a classic cycle model, namely, case retrieval, case reuse, case revision, and case retention (4R) [1]. Applications of CBR in fault diagnosis and fault prediction have received a substantial amount of attention, for example, a fault prediction model was established using CBR to evaluate the possibility of each possible fault in a shaft furnace's status. Indicators such as the missed alarm rate have been improved by performing fault predictions based on CBR [31]. In addition, the hybrid applications of CBR and other intelligence technologies have been discussed. A synthesizing hybrid system with a neural network and CBR was presented to address the diagnosis problem of electric motors with a relatively high level of accuracy [27,33]. However, the results of the CBR method depend on the richness of experience and their learning ability. To predict the process accurately by CBR, a weight allocation of the attributes and a case revision should be considered.

To realize the real-time prediction of the furnace condition, an improved CBR-based fault prediction method (ICBRP) containing water-filling theory (WFT) and group decision-making (GDM) is introduced in this paper. First, the furnace condition is modeled by the case representation method using a characteristic value description. Then, a Lagrange function is constructed to calculate the weights of the case features via the WFT. The credibility of each group of historical prediction results is defined and used to revise the prediction results for the target case by the GDM. The proposed method can obtain more reasonable attribute weights and can take full advantage of the retrieval information. Finally, the proposed method is applied to the roasting process of shaft furnaces, the fault prediction system is researched and developed, and it is shown that the contrasting results of the receiver operating characteristics (ROC) graph, the missed alarm rate and false alarm rate illustrate that the improved CBR method does, in fact, have advantages when used in an application.

This paper is organized as follows. Section 2 introduces the shaft furnace roasting process and its fault mode. Section 3 presents the structure, functions and algorithm for the fault prediction model of the shaft furnace status. Section 4 introduces the experimental results. Conclusions and further research are then discussed in Section 5.

2. Problem formulation

The technical process of shaft furnace roasting and its possible faults are shown in Fig. 1. The heating air flow and heating gas flow are adjusted by the frequent conversion speed changing motor (V1) and control valve (V2), respectively. At both sides of the shaft furnace, heating air and heating gas are mixed to burn in combustion chambers. The heat from the combustion chamber can raise the temperature of the falling ore to 700–850 °C. Then, the heated ore enters the reduction zone, where its temperature falls to approximately 570 °C, and the ore is reduced by the reduction gas, which is regulated by a valve (V3), with the product being strong magnetism. The carrier motor (V4) is triggered to move the roasted ore out of

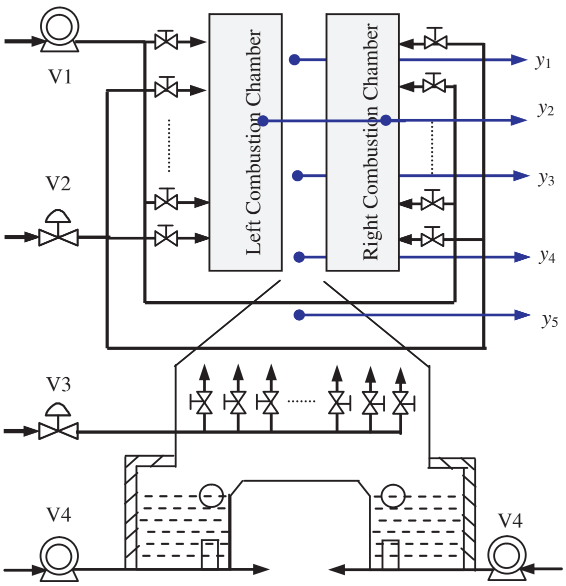

Fig. 1. The technical process and faults of the shaft furnace roasting.