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Cluster analysis based on attractor particle swarm optimization with boundary zoomed for working conditions classification of power plant pulverizing system

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A B S T R A C T

This paper proposes a cluster analysis method based on Attractor Particle Swarm Optimization with Boundary Zoomed (APSO-BZ) for working conditions classification of power plant pulverizing system. The proposed method could be used on the field data directly and the obtained clusters represent the different working conditions of the power plant pulverizing system. For APSO-BZ, the particle position is updated based on the attractor which equals the random modified value of the own optimal or the global optimal. The boundary zoomed strategy is presented for letting a particle flying outside of the search space be relocated based on the positions of the particle and the attractor. Moreover, the sum of the symmetrical compactness of each cluster is adopted as the fitness function for APSO-BZ. Three real-life datasets from UCI Machine Learning Repository and a field dataset of a real power plant pulverizing system are adopted to evaluate the effectiveness of the proposed method. The experiments results verify that the proposed method has higher clustering capability and avoids the premature convergence under a certain extent. Moreover, the proposed method would implement the working conditions classification more correctly.

1. Introduction

Pulverizing system provides the coal powder for the boiler and is one of the major equipments in a thermal power plant. The coal insufficient and the clogging would affect the working safety of pulverizing system. Moreover, pulverizing system has high energy consumption and it would use 15%–25% of the whole energy consumption of the thermal power plant [1]. Estimating the unusual running state and ensuring the pulverizing system to be at the best efficiency are of important theoretical significance and practical motivation for the safety operation and the energy saving. Because pulverizing system is a multi-variable, nonlinear, strong coupling and time-varying complex system [2], the operation characteristics are different under the different working conditions. Hence, the classification of working conditions is the premise of realizing the process monitoring and the control optimization for the pulverizing system.

Cluster analysis groups a set of objects into some classes [3], and the objects in the same class are more similar than those in different classes. So, cluster analysis could be used to classify the working conditions of pulverizing system. K-means is the most well-known clustering analysis method and is implemented easily [4,5]. The fuzzy c-means (FCM) algorithm is a fuzzy extension of the k-means and has achieved success in image segmentation [6], product cost forecast [7] and electric power system control [8]. Since k-means and the FCM could not find the clusters of different size densities and have trouble clustering data that contain outliers [9], some clustering algorithms based on k-means and FCM are presented [10–14]. However, in a real-world dataset, the data are characterized by some attributes, each of which could be regarded as an independent parameter of the dataset. Since these clustering methods would not deal with the complex interrelationships between the various attributes of the dataset, they may not be suitable for the field database of pulverizing system which is complex and there exists coupling between dimensions of database (if the process variables of the pulverizing system are deemed as the dimensions of the database). In addition, since these clustering algorithms based on k-means and FCM start with an initial estimation of the cluster center, the clustering results may be suboptimal. Hierarchical clustering is also an important cluster analysis method and works by grouping the objects into a tree of clusters. Since the hierarchical clustering approach decides which clusters should be merged at each step, namely, decision of merging two clusters cannot be undone at later time, it may not be viewed as globally optimizing method. Furthermore, the time complexity and the space complexity may hamper its application [15]. Because the cluster analysis

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could be viewed as a NP-hard grouping problem, various heuristic algorithms are used to determine the best number of clusters according to the given objective function [16–19]. Particle swarm optimization (PSO) is an efficient search algorithm and some discussions of PSO attracted much interest from the researchers in recent past years [20–22]. PSO adjusts the individual position according to the information obtained by its neighbor connections, which is same as the clustering algorithm analyzing the relationship between objects [23]. Hence, PSO turns out to be potentially attractive for being applied to cluster analysis [24,25]. Although PSO has no evolution operators and easy to be implemented, it may be trapped in the local optima, which is similar to other searching algorithms [26]. Moreover, the problem of overshooting particles may happen over the course of iterations [27].

In this paper, we proposed a cluster analysis method based on attractor particle swarm optimization with boundary zoomed (APSO-BZ) for working conditions classification of power plant pulverizing system. The proposed method performs the clustering analysis based on APSO-BZ on the field data of pulverizing system and the obtained clusters represent the different the working conditions. The sum of the symmetrical compactness of each cluster is adopted as the fitness function for APSO-BZ, and each particle randomly chooses the own optimal or the global optimal to calculate the attractor, then the particle position is updated based on the attractor. Since the attractor allows the particles to search the new areas, the probability of trapping in local optima would be decreased. Moreover, the boundary zoomed strategy is presented for letting a particle flying outside of the search space be relocated based on the positions of the particle and the attractor. The boundary zoomed strategy dose not destroy the swarm structure and could ensures every particles, including the overshooting particles, be in the searching process without information loss, so the global exploration ability is enhanced and the clustering effectiveness is improved. Three datasets of UCI Machine Learning Repository and a real dataset obtained from the field database of power plant pulverizing system are used in the experiments for estimating the effectiveness of the proposed method.

The organization of this paper is as follows: Section 2 provides some preliminaries and the problem statement. The proposed method is presented in detail in Section 3. In Section 4, the experiments are presented to verify the effectiveness of the proposed method. Finally, Section 5 concludes the paper.

2. Preliminaries and problem statement

The schematic representation of a pulverizing system is shown in Fig. 1. The raw coal is fed into the ball mill for being pulverized to the coal powder. At the same time, the hot air, the cold air and the recycle air are used to dry and deliver the coal powder, respectively. The coal powder is sent into the coarse classifier and fine classifier. The accepted powder is stored in the pulverized coal bunker and the unqualified powder is fed back into the ball mill for further pulverizing. The mill exhauster provides the power for the flow process of the air-powder mixture. The recycle air is from the outlet of the mill exhauster.

In general, there are twelve process variables in the pulverizing system. All of them are related to the working conditions of pulverizing system in a certain extent and the characteristics of these variables are discussed in the following.

The ball mill load (l_{bm}) is the ratio between the volume of coal powder in the mill and the interstitial volume of the static ball charge [28]. l_{bm} is related to the pulverizing capability, which representing the efficiency of pulverizing system. The pulverizing capability would increase with the l_{bm} increasing. However, the larger ball mill load may lead the ball mill to be clogged.

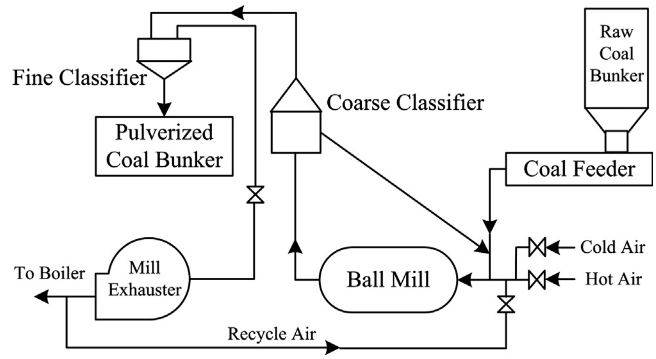

Fig. 1. Pulverizing system of thermal power plant.

The inlet negative pressure of ball mill (inp_{bm}) is used for monitoring the pulverizing system whether works under the negative pressure state. If inp_{bm} is not enough high, the coal powder would not be transferred efficiently. If inp_{bm} gradually increases until converts to positive pressure, the coal powder would spray outside, that would cause the bodily injury and the environmental pollution.

The outlet negative pressure of the ball mill (onp_{bm}), the outlet negative pressure of the coarse classifier (onp_{cc}) and the outlet negative pressure of the fine classifier (onp_{fc}) are three important measuring points from the outlet of ball mill to the inlet of mill exhauster. When the pulverizing system working normally, the absolute values of onp_{bm}, onp_{cc} and onp_{fc} increase successively and the pressure difference between each two adjacent measuring points is in a fixed range. Otherwise, there may be piping blockage in pulverizing system.

The outlet negative pressure of the mill exhauster (onp_{me}) and the ventilation rate (vr) represent the air draft capability of pulverizing system and they are usually affected by working state of mill exhauster and the opening degree of inlet baffle of mill exhauster. Furthermore, the measuring point of vr is in the vertical pipe of the outlet of ball mill.

The different inlet–outlet pressure of the ball mill (dp_{bm}) sometimes is used for estimating the pulverizing capability. If the effective flow area of ball mill decreases and the flow resistance of ball mill increases, dp_{bm} become larger. On the contrary, dp_{bm} would decreases. Therefore, dp_{bm} mainly represents the clog situation of coal powder in pulverizing system.

The inlet temperature of the ball mill (it_{bm}) and the outlet temperature of the ball mill (ot_{bm}) represent the drying capability of pulverizing system for coal powder. The drier the powder coal is, the more easily it is pulverized. However, it_{bm} and ot_{bm} should be controlled in the suitable value respectively. Letting the outlet temperature be higher would be a risk that the coal powder may be ignited.

The motor current of the ball mill (mc_{bm}) is nonlinearly related to l_{bm}. When l_{bm} is small, mc_{bm} increases with l_{bm} increasing. Nevertheless, when l_{bm} is very large, namely, the ball mill is closes to full, mc_{bm} would decrease with l_{bm} increasing.

The motor current of the mill exhauster (mc_{me}) would affected by vr and could indirectly represent the pulverizing capability.

According to the analysis mentioned above, l_{bm}, inp_{bm}, onp_{bm}, onp_{cc}, onp_{fc}, onp_{me}, vr, dp_{bm}, it_{bm}, ot_{bm}, mc_{bm} and mc_{me}, would be used for working conditions classification of power plant pulverizing system.

3. The proposed method

We present a cluster analysis method based on APSO-BZ for classifying the working conditions of pulverizing system.