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# Intelligent fault recognition strategy based on adaptive optimized multiple centers

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ABSTRACT

For the recognition principle based optimized single center, one important issue is that the data with nonlinear separatrix cannot be recognized accurately. In order to solve this problem, a novel recognition strategy based on adaptive optimized multiple centers is proposed in this paper. This strategy recognizes the data sets with nonlinear separatrix by the multiple centers. Meanwhile, the priority levels are introduced into the multi-objective optimization, including recognition accuracy, the quantity of optimized centers, and distance relationship. According to the characteristics of various data, the priority levels are adjusted to ensure the quantity of optimized centers adaptively and to keep the original accuracy. The proposed method is compared with other methods, including support vector machine (SVM), neural network, and Bayesian classifier. The results demonstrate that the proposed strategy has the same or even better recognition ability on different distribution characteristics of data.



## 1. Introduction

Fault recognition is a vital link of fault diagnosis, which is defined to determine the true states of the unknown fault patterns accurately. Actually, it has been widely and successfully applied to recognize running states of many complicated equipments, such as aeroengine, rotating machinery, and power electronic system [1–5]. It obviously helps to improve the efficiency of trouble-shoot, shorten the maintenance period, reduce the maintenance costs and ensure production safety. On the other hand, with the rapid development of industrial equipment, traditional analytical models can hardly describe real operations of complicated, huge and integrated equipment, and thus, the intelligence methods, such as including artificial neural network, statistical pattern recognition, swarm intelligence, and kernel-based algorithms, are paid more attentions, and have promoted the development of fault diagnosis technology in a more practical direction [6–8].

The advantage of intelligent fault recognition methods always focuses on dealing with the monitoring data of the running states without caring the physical or chemical running processes of equipment. Therefore, the methods can avoid the complicated mathematical description for the running process of the diagnosis object [9,10]. Meanwhile, with the development of intelligent computation, intelligent algorithms imitating natural phenomena of biological or physical systems can fully reflect the intelligent information processing mechanism contained in various systems, such as swarm intelligent algorithms simulating foraging behaviors of social animals [11,12], evolutionary algorithms deriving from the principle of the evolution-

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ary laws in the biological world [13,14], and artificial intelligent algorithms based on behavior patterns, logic thinking and brain characteristics of human [15,16]. Undoubtedly, they have been widely used to solve various real-world problems, especially in the field of fault diagnosis.

The particle swarm optimization (PSO) algorithm is a classic of swarm intelligent algorithms, due to concise mathematical expression, good self-organization and adaptive performance, explicit individual interaction relationship. The PSO has developed rapidly and different well-known PSO variants were proposed to overcome the premature convergence problem caused by trapping into local suboptimal areas [17–19]. Furthermore, fitness functions, as a vital part of algorithm, are designed for specific applications, such as optimization design, feature extracting, path planning, and data clustering [20–23]. Although many studies on PSO always focus on its optimization applications, some studies try to apply PSO into pattern recognition, after the clustering algorithm based on PSO was proposed firstly in 2002 [24], the applications of PSO in pattern recognition and data mining increase rapidly [25–27]. In recent years, the applications of PSO have been extended to the field of prognostics and health management (PHM) [28–30]. Via combining with other classifiers, PSO variants improved the diagnosis and prognostics performances of classical classifiers, such as SVM [10,31–33], neural networks [7,34,35]. Zheng et al. [29,30] used the PSO variants to optimize a single center for each class, and the optimized single centers can meet the requirement of shorter intra-class distance, longer inter-class distance and maximum classification accuracy of training samples, so unknown samples can be recognized by comparing their distances with the optimized single centers. Virtually, the optimization of single center meeting three objectives is transformed to a single objective optimization problem. The significance of the studies is that the PSO becomes an independent classifier, not just an optimizer.

As a classifier, the experimental results [29,30] demonstrate that the performance of PSO variants is superior to other classical algorithms when applying to some data sets. Of course, no free lunch (NFL) theorem indicates that any pattern recognition algorithm cannot hold the superiority in its blood, it is impossible to be effective for all problems [36]. Consequently, the recognition principle based on distance from optimized single center to unknown samples has some obvious defects for some data sets. In other words, some data sets cannot be recognized accurately depending on only an optimized single center. Therefore, based on previous studies, this research will focus on the improvement of the principle based on optimized single center, and make the improved recognition method cope with more data sets.

In this paper, to solve the problems of the recognition principle based on the optimized single center, a novel recognition strategy is proposed. Moreover, using the optimization capability of PSO, a multi-objective optimization problem is constructed to meet more specific targets. Eventually, the accuracy is a prerequisite for fault recognition, so it must be met firstly as a primary objective, and on the basis of meeting first objective, other objectives, such as the quantity of optimized centers, the relationship of intra-class distances and inter-class distances, will be reconsidered and get new optimized results. Therefore, the strategy is based on adaptive optimized multiple centers.

On the other hand, the multi-team competitive optimization (MTCO) algorithm based on the traditional PSO has been demonstrated that it has globally stable and optimal performance [30], which is also a PSO variant. This algorithm is inspired by competitive behaviors of multiple teams. It is a three-level organization structure. And aim to searching more potential optimal areas, by imitating human thinking, the MTCO algorithm is conducive to get rid of the premature convergence effectively, and overcome the influence of randomness on the optimal decision solution. Thus the global optimal solution can be obtained with a higher probability. In this paper, it is noted that the MTCO algorithm is introduced as optimizer because of its better optimization and recognition performance. The detail description of MTCO algorithm can be found in Ref. [30].

The rest of the paper is organized as follows. In Section 2, the defects of the recognition principle based on optimized single center are analyzed. In Section 3, how to improve the appropriate optimized centers is discussed in detail. Section 4 compares the performances of the proposed method and some commonly used recognition methods, and proves the merits of multiple centers. After that, the proposed method is applied to the fault recognition to verify the effectiveness of multiple centers. Finally, in the last section, conclusions are drawn.

## 2. The defects of recognition principle based optimized single center

Zheng et al. [29,30] analyzed the performance of the recognition principle based on optimized single center, which has been demonstrated in Fig. 1. Obviously, the recognition principle can be classified into the method based on distance. In fact, *k*-nearest neighbors (*k*-NN) algorithm, learning vector quantization (LVQ) network, SVM, and so on, they are based on distance. The recent studies have indicated the defects of these algorithms, for examples, the *k*-NN is very sensitive to the parameter *k*, the different values of parameter *k* will severely affect the application of *k*-NN; and the defect of LVQ network has been discussed detailedly in Ref. [34] due to its non-identifiability for unknown samples and non-uniqueness for classification results; although the kernel function is introduced into SVM so that it can cope with the nonlinear distribution data, the common SVM can only recognize the two-class data [37]. Undoubtedly, the recognition principle based on optimized single center also suffers from defect.

As shown in Fig. 1, it depends on the distance from an unknown sample to the optimized centers, *i.e.*, if the distance from an unknown sample to the optimized center 1 is the shortest, this unknown sample should be classified into Class 1. Meanwhile, the methods are also verified by some classic data sets, and applied to the real-world fault recognition. The results show that the performance of the proposed methods is robust; their recognition accuracies are higher than other popular methods, such as SVM, and LVQ network [29,30].