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Induction machine fault detection using clone selection programming

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ABSTRACT

A clonal selection programming (CSP)-based fault detection system is developed for performing induction machine fault detection and analysis. Four feature vectors are extracted from power spectra of machine vibration signals. The extracted features are inputs of an CSP-based classifier for fault identification and classification. In this paper, the proposed CSP-based machine fault diagnostic system has been intensively tested with unbalanced electrical faults and mechanical faults operating at different rotating speeds. The proposed system is not only able to detect electrical and mechanical faults correctly, but the rules generated is also very simple and compact and is easy for people to understand, This will be proved to be extremely useful for practical industrial applications.

1. Introduction

In general, induction machines are important and expensive devices in certain industries, such as manufacture, transportation. They play the essential role for industrial success so that the maintenance of them is essential and profitable to most electrical industrial processes. If the lifetime of induction machines was extended, and efficiency of manufacturing lines was improved, it would lead to smaller production expenses and lower prices for the end user. In order to keep machines in good condition, some techniques i.e., fault monitoring, fault detection, and fault diagnosis have become increasingly essential (Isermann, 1997; Leohardt & Ayoubi, 1997; Patton, Frank, & Clark, 1989). Although there are different types of methods used for detecting machine faults (Ye & Wu, 2000), the use of vibration signals for fault detection and diagnostic analysis has widely recognized as a reliable approach.

Most signal processing techniques applied to machine fault diagnostic analysis are in either the time domain or the frequency domain. Although the information about the rotating machine conditions can be obtained through the vibration signal transmitted through the machine casing, it is still a difficult task to determine the machine conditions from the measured vibration signals. Although there are a number of different approaches reported for performing machine fault diagnostic analysis, such as time-domain analysis (Lipovszky et al., 1990; Ragulskis & Yurkauskas, 1989), probabilistic analysis (Lipovszky et al., 1990; Ragulskis & Yurkauskas, 1989), and finite-element analysis (Donley, Stokes, Jeong, Suh, & Jung, 1996), frequency-domain analysis appears to be the most popular and computational non demanding approach for providing the required information, which is totally attributed to the more salient characteristic features in the frequency domain.

Machine fault detection is classified invasive and noninvasive methods (Chow & Methedologies, 1997; Chow, Sharpe, & Hung, 1993). The noninvasive methods are more preferable than the invasive methods because they are based on easily accessible and cheap measurements to diagnose the machine conditions without disintegrating the machine structure. The common types of machine fault diagnostic in the frequency domain include bearing defect frequency analysis (Collacott, 1979; Dimarogonas, 1996), high-frequency shock pulse and friction forces methods (Collacott, 1979; Dimarogonas, 1996), enveloped spectrum methods (Collacott, 1979; Dimarogonas, 1996), high-order-spectrum (HOS) methods (Chow, 2000; Chow & Fei, 1995), and wavelet methods (Tse, Peng, & Yam, 2001; Wang, 2001) etc. Recently, artificial intelligence (AI) techniques have been proposed for the noninvasive machine fault detection (Chow & Methedologies, 1997; Filippetti, Franceschini, Tassoni, & Vas, 2000). They have several advantages over the traditional model-based techniques (Chow & Methedologies, 1997; Filippetti et al., 2000). They require no detailed analysis of the different kinds of faults or modeling of the system. These AI-based techniques include expert systems, neural network, and fuzzy logic etc. An expert system is able to manage knowledge-based production rules that model the physical system (Filippetti et al. 2000). Neural network approaches can be considered as "black-box" methods as they do not provide heuristic reasoning about the fault detection process (Chow & Methedologies, 1997; Chow et al., 1993). Fuzzy logic systems can heuristically implement fault detection principles and heuristically interpret and analyze their results (Chow & Methedologies, 1997). There are a few papers reporting unsupervised neural network as diagnostic preprocessor for classification purpose (Penman & Yin, 1994; Schlang, Habetler,

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& Lin, 1997), while supervised neural network approaches (Alguindigue, Buczak, & Uhrig, 1993; Chow & Mangum, 1991; Filippetti, Franceschini, & Tassoni, 1995) can be used for fault and fault severity classification. The supervised neural networks in Alguindigue et al. (1993), Chow and Mangum (1991), Filippetti et al. (1995) are multilayered networks (MLNs). Coupled with the backpropagation (BP) algorithm, the MLNs fall short for their slow convergence rate and local minimum problem (Er, Wu, Lu, & Toh, 2002). On the other hand, RBF neural networks have drawn extensive interest because of its well-known classification performance compared with MLNs (Er et al., 2002). But it requires the many trial tests to determine the appropriate network architecture, which is not user friendly for general industrial applications. Sitao Wu et al. presented a self-organizing-map (SOM)-based radial-basis-function (RBF) network (Wu & Chow, 2004) for fault diagnostic classification. It can automatically select the centers and the number of hidden neurons of the RBF networks to determine the appropriate network architecture so that machine fault detection accuracy is higher. A great deal of references has proven the success of these neural networks for machine fault detection. But, the generations of these classifiers are difficult for layman to understand and implement. This prevents classifiers from being widely used in most machine fault detection applications.

Genetic Programming (GP), first introduced by Koza (1992), is derived from GA. In the short period of its development, GP has been successfully applied in many fields, including condition monitoring (Kojima, Kubota, & Hashimoto 2001; Helmer et al., 2002; Cheng & Chiu, 2005). In fact, the GP based classifier is a kind of the rule-based classifiers, which can build a set of IF-THEN rules according to a training dataset S whose instance has some attributes and a unique target class label so that the target accuracy for new unseen data can be predicted. So when it is applied into fault detection, it can generate some rules to discriminate whether machine exists fault or not, which will make people analyse and understand the reason of the fault. Liang Zhang et al. applied GP into roller bearing fault detection successfully (Zhang & Lindsay, 2005; Zhang & Nandi, 2006), the experimental results show that the classification rules derived are easily understood and capable of independent verification on other data. However, it is not reported that GP is applied into induction machine fault detection.

Due to the tree type structure, GP can express complex relationship between the observed data using any combinations of logical, mathematical functions of input attributes. Thus, GP can provide a better solution structure adaption to the data compared with GA. Therefore, GP can find more accurate and complex classification rules than GA. But compared with GA, GP has much larger searching space, so it consume more time than GA. In additional, GP cannot keep syntax closure property during evolution. Moreover, GP's tree-based individuals typically result in bloating (Zhang & Muhlenbein, 1995).

The classifier based on GP for two class problems has been successfully elaborated and applied into classification of medical data (Dounias et al., 2002; Falco et al., 2002; Stanhope & Daida, 1998). Although many researchers use genetic algorithm to design classifiers for multi class problems, only a few GP methods have been made to solve multi class problem (Bojarczuk, Lopes, & Freitas, 2000; Chien, Lin, & Hong, 2002; Dounias et al., 2002; Kishore, 2000; Lim, Loh, & Shih, 2000; Mendes, Voznika, Freitas, & Nievola, 2001). Usually, people consider a c class problem as a set of c two-class problems (Kishore, 2000), which is called ''binary decomposition'' (Brodley & Danyluk, 2001) or ''one-against-all learning'' (Loveard & Ciesielski, 1983). For a c class problem, the system is run c times, so, the efficiency of the system is not high. For a c class pattern classification problem, another method for designing classifiers is just using a single run of GP. A multi tree classifier having c trees is constructed, where each tree represents a classifier for a particular class. The performance of a multi tree classifier depends on the performance of its corresponding trees. Compared with ''one-against-all learning'' method, it is direct and demonstrates more high efficient. Muni et al. (2004) have designed a multi tree classifier using GP solve this question successfully.

Artificial immune system is a kind of methodology inspired by the human immune system. Research on artificial immune system (de Castro & Timmis, 2002; Wierzchon, 2002) has become increasingly popular in the area of evolutionary computing. New models of artificial immune system are proposed, and more applied research have been explored, such as computer security, data mining, clustering, pattern recognition and function optimization etc (Cutello, Nicosia, Pavone, & Timmis, 2007; de Castro & Von Zuben, 2000; Watkins, Timmis, & Boggess, 2004). Despite the flourishing of artificial immune system in some areas, there is only a handful of papers (Sahan, Kodaz, Güneş, & Polat, 2004; Watkins et al., 2004) focused on the design of classifier using artificial immune system. The research on immune programming is even fewer, and until now the rule-based classifier using artificial immune system has not been reported in literature.

We have proposed a new programming method, called clone selection programming (CSP) (Gan et al., 2008) based on the theories of the immune system to enhance the effectiveness of programs encoding and search engine. The newly proposed CSP can become a powerful tool applied widely into artificial intelligence and machine learning etc. field. Compared with other approaches based on artificial immune system, clone selection programming (Gan et al., 2008) based method can significantly improve the program performance. In this paper, we extend clone selection programming to the design of classifier for machine fault detection. A kind of master/slave-style parallel computing multi thread model was proposed to improve the performance of evolutionary search of CSP. After the vibration signals are transformed into the frequency domain, four characteristic features vectors are extracted from the power spectra in the frequency domain as inputs of the proposed clone selection programming based classifier. The advantages of the proposed CSP-based classifier are twofold. First, the classifying rules established by using our proposed method are comprehensible and capable of independent verification on other data. In addition, these fault detection rules are more compact than ones established by GP classifier. Second, CSP-based classifier is very easy to implement and does not require the many trial tests to determine the appropriate parameters. This feature is user friendly for general industrial applications.

The experimental results demonstrate that our CSP-based approach is promising for detecting machine faults via monitoring the vibration signals.

The presentation of this paper is organized as follows. In Section 2, we briefly describe how the four characteristic features are extracted from the power spectra after the signals are transformed into the frequency domain. In Section 3, clone selection programming and our proposed classification strategy are detailed. In Section 4, two types of machine faults including ''electrical faults,'' and ''mechanical faults'' were used for system validation. Finally, conclusions are drawn in Section 5.

2. Preprocessing of vibration signals

Vibration is the best indicator of overall mechanical condition and the earliest indicator of defects developing. Vibration analysis is based on the principle that faults can be detected in characteristic frequencies associated with particular type of faults in the frequency domain. The basic fault detection system in the frequency domain is briefly shown in Fig. 1. First vibration signals are collected from transducer based data acquisition systems. Then the signals are transformed by fast Fourier transform (FFT) into signals