Journal of Physics: Conference Series

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To cite this article: Sanchuan Xu 2019 *J. Phys.: Conf. Ser.* **1187** 032006

IOP Conf. Series: Journal of Physics: Conf. Series **1187** (2019) 032006 doi:10.1088/1742-6596/1187/3/032006

A SURVEY OF KNOWLEDGE-BASED INTELLIGENT FAULT DIAGNOSIS TECHNIQUES

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Abstract. With the development of information technologies, more and more real-time data can be obtained from production and operation process. Thus, how to extract effective information from these massive data, so as to carry out in-depth statistics and mining of faults, and gradually explore the faults laws and causes are crucial for intelligent factories. In recent years, a variety of statistical learning and data analysis methods have been used in fault diagnosis. Due to the complex structure, multi-source failure and suddenness of the industrial production system, the combination of empirical knowledge and mechanism principles can solve various fault problems. This paper summarizes several commonly used fault diagnosis methods, and focuses on knowledge-based intelligent fault diagnosis, including first-order logic knowledge representation method, production knowledge representation method, framework knowledge representation method, object-oriented knowledge representation method and Semantic-based knowledge representation methods.

1. Introduction

Fault diagnosis is a sub-area of control engineering, which is a multidiscipline intersection product. As far as current research is concerned, Modern Control Theory, Signals and Systems, pattern recognition and other disciplines have been applied into fault diagnosis. The development of fault diagnosis technology will greatly depend on the mentioned disciplines. The basic concept of fault diagnosis is to recognize the failures of the system and determine their types and location in time when the failures occur by monitoring the system.

The whole diagnosis system consists of three parts. They are named fault detection, fault recognition and fault recovery respectfully, which is shown in Figure 1. The concepts of these three parts are described in detail as below.

1) Fault detection: determine whether fault occurs in time. Should there be a fault, the alarm would go off and certain action would be taken to prevent further catastrophic consequence.

2) Fault recognition: after the detection of fault, the module should confirm which fault occurred, which component is dysfunctional. Then confirm the type, location, hierarchy and occurring time of the fault, at the same time, identify the cause of the fault.

3) Fault recovery: establish corresponding countermeasures according to possible adverse effects to ensure the normal operation of the system or to avoid catastrophic errors in system.

In this article, we will focus on the detection and recognition of the fault.

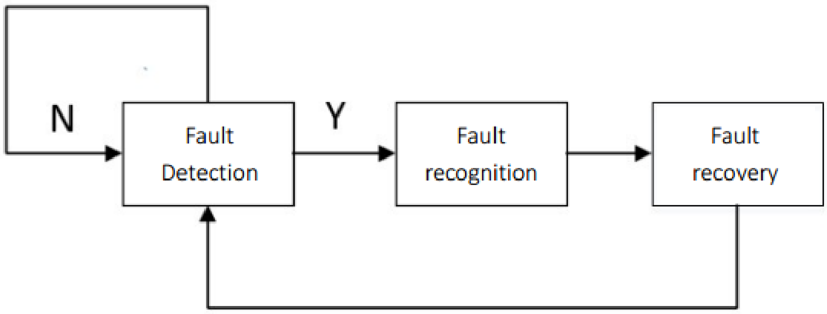

Figure 1 Fault Diagnosis System

2. Classification of the fault diagnosis methods in industrial process

At present, the methods of fault diagnosis can be generally divided into three categories: analytical model driven method, signal processing driven methods, and knowledge driven methods.

Analytical model-driven methods can be traced back to the 1971 doctoral thesis “Failure Accommodation in linear systems through self-reorganization” published by Massachusetts Institute of Technology, Beard. Its basic idea is: before and after the fault occurs, the system is performing normal and error respectively. An analytical model is established while the system is performing normally. By comparing the model output with the measured output of the system, a fault indicator called the “residual” is generated. This indicator, if the fault occurs, will affect the measure output of the system, resulting in the residual exceeding the threshold. At this point, it can be determined that a fault has occurred. By further analysis and evaluation of the residual, it is possible to provide information about fault separation and estimation information. The downside of this approach is the need to obtain accurate mathematical models of the system, which is often difficult to achieve in practice.

For many actual systems, it is difficult to accurately establish an analytical model of the diagnostic object. At this time, the signal model can be used to directly extract the fault feature information. Common signal processing driven fault diagnosis methods include: fault diagnosis method based on wavelet transform, δ operator-based method, principal component analysis method, method for detecting fault using Kullback information criterion and so on [2].

Wavelet transform is a branch of applied mathematics developed in the late 1980s. Ye et al. studied its application in dynamic fault detection and simulated it to obtain satisfactory results. It is a promising fault diagnosis method. Xiao Deyun et al. constructed a fault detection filter based on the δ operator. However, as it is unable to eliminate fault information, the filter may still send alarm after the fault’s disappearance, which makes it difficult to generalize in practice. Sang et al. introduced the KPCA (kernel principal component analysis) method into the dynamic fault detection of nonlinear systems and compared it with the traditional PCA method. The simulation results show that the false positive rate is significantly reduced. Kumamaru et al. introduced the Kullback information criterion into fault detection. The basic idea is to compare the KDI (Kullback Discrimination Information) with the set threshold to detect system faults.

In recent years, due to the rapid development of artificial intelligence and computer technology, fault diagnosis methods based on the knowledge have gradually attracted people’s attention. This method does not require knowledge of the exact mathematical of the object. It can be mainly divided into: neural network fault diagnosis method, fuzzy fault diagnosis method, expert system fault diagnosis method, support vector machine fault diagnosis method and so on. Yan Mingzhong et al. used the neural network for the fault diagnosis of underwater robots and compensated for the fault conditions to ensure the stable operation of the robot. Hacene Habbi et al. applied the fuzzy mathematics method to the fault diagnosis of aircraft heat exchangers. The results showed that it could effectively detect and isolate the sensor and actuator faults of heat exchanger. Lin Jiliang et al. used the support vector machine for the fault classification of mobile robots. The experimental results show that the method of using wavelet transform to extract the feature vectors, then classifying the faults using the support vector machine classification have a very good result.

It is worth mentioning that various fault diagnosis methods are not independent but can cooperate with each other. Figure 2 shows the various fault diagnosis methods and their categories.

3. Knowledge-based fault diagnosis methods

Knowledge-based fault diagnosis methods can effectively make use of expert knowledge and experience to make judgements. In some fields, when constructing the fault ontology, the researchers would model the relationship between the fault phenomenon and the cause, and then use the ontology reasoning technology to diagnose. However, in the actual fault diagnosis process, there is usually an uncertain relationship between the fault phenomenon of the equipment to be inspected and the cause of the fault. To better meet the needs of knowledge-based fault diagnosis, this paper reviews the research status of knowledge representation, fault knowledge construction and fault knowledge representation and acquisition.

In the field of artificial intelligence, the focus of Knowledge Representation is to use computers to realize the formal expression and information acquisition of knowledge. Therefore, knowledge representation methods and systems can be used to solve complex problems.

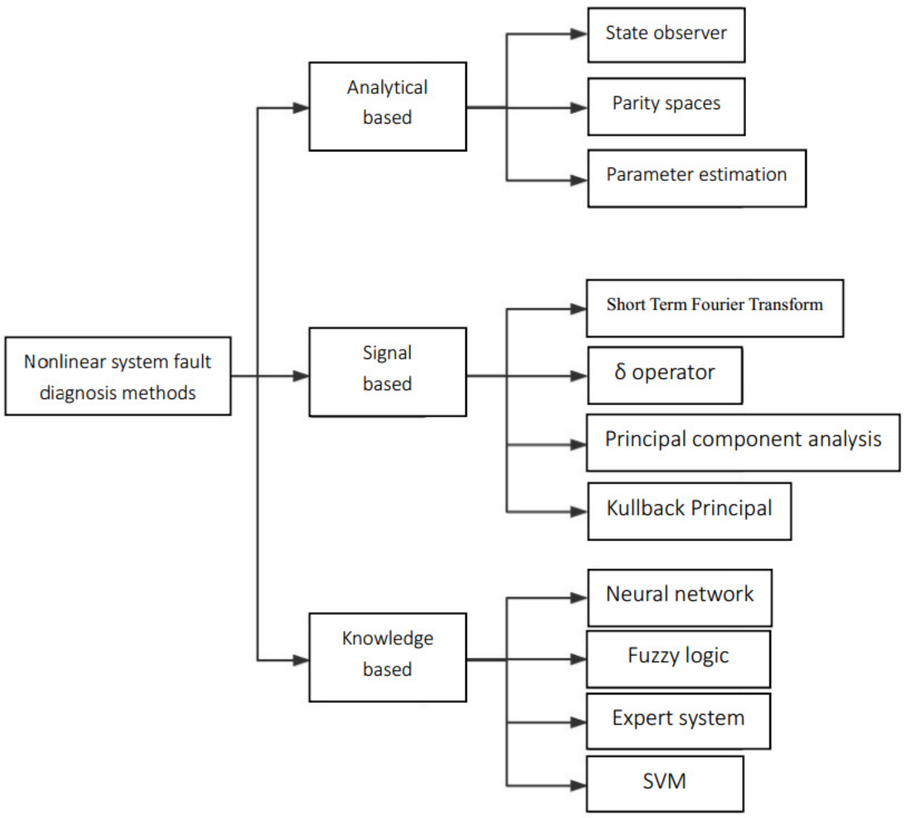

Figure 2 Fault Diagnosis Methods Categories

(1) First-order logic knowledge representation

Predicate logic knowledge representation is the earliest representation method applied to artificial intelligence. Its purpose is to apply the logic arguments in mathematics to express the law of human thinking activities. So far, the predicate logic knowledge representation method is the most accurate formal language. Liang et al. used the synchrophasor measurement data collected from a power grid to form diagnosis rules for wide-area fault detection [11]. Based on the mined knowledge, three common types of short circuit faults, single-line-to-ground, line-to-line, and three-phase faults, are identified in the power grid.

(2) Production knowledge representation

The expression of the production knowledge representation is: if A then B. The relationship between concept and concept established by production knowledge representation is also the basis of knowledge representation. In the process of development, fuzzy knowledge representation and reasoning can be effectively processed through the improvement of technology. With the fusion with particle swarm optimization algorithm, the function of weighted fuzzy reasoning is improved. Deng et al. conducted fault diagnosis of electronic protective equipment based on CBR (case-based reasoning) by using K-NN Similarity Algorithm and Semantic Feature Vector pattern [12].

(3) Framework knowledge representation

The framework representation can express the internal structural relationship of knowledge and the connection between knowledge. It also can represent the inheritance relationship between knowledge. This is the same with the way of thinking when humans observe things. It has the characteristics of strong adaptability, high generality, good structure and flexible reasoning. Liu et al. developed an object-frame knowledge model which is made up of state-object, test-object and rule-object or repair-object, then used the forward chaining strategy to implement fault reasoning for a meteorological vehicle system [4].

(4) Object-oriented knowledge representation

Object-oriented knowledge representation is a combination of static attributes and dynamic operations. It conforms to people's habitual thinking mode of understanding and analysing problems, and has the characteristics of modularity, encapsulation, inheritance, polymorphism and easy maintenance. Since object-oriented knowledge represents structural and operational characteristics, this method has been applied in various fields such as product design and production, fault diagnosis, biomedicine, and chemistry. Dattatraya et al. used an object-rule structure to represent the procedural knowledge in complex electronics systems, ARM processor boards and large embedded systems and demonstrates the approach’s effectiveness in fault diagnosis [3].

(5) Semantic network knowledge representation

The semantic network knowledge representation system matches the network segment of the problem with the knowledge base network segment and finds the solution of the problem according to the structure matchmaking. Semantic network knowledge representation can define relationships between objects artificially at any time as needed. It is structural, natural, associative and non-strict. Martin et al. applied ontologies to model the correlations, constraints, and dependencies among different system parts, and used ontology reasoning to identify the root cause of faults in complex products [10]. Niu et al. used ontology to represent the fault phenomena and properties, and further modelled the fault diagnosis problem as a bipartite graph match problem, which was efficient for fault diagnosis of complex system [1].

In the field of fault diagnosis, different methods are used to describe fault diagnosis knowledge, such as production, oriented object, script, semantic network, Petri net, ontology, causal network, and bond graph. However, the complexity of fault diagnosis makes it difficult to achieve the desired effect by any single method. Therefore, researchers try to solve the problem of multi-knowledge expression through different methods. For example, Son et al. adopted the method of fusing multiple expression methods; the concept of the Expert System Shell was proposed; the cross-hybrid model was proposed, and the knowledge interoperability of large-scale knowledge bases was proposed.

4. Conclusion and future work

Industrial production line is a complex system integrating mechanical, electrical, hydraulic and pneumatic pressures. Its fault occurrence has the characteristics of multi-source, correlation, suddenness and randomness. The acquisition cannot meet the needs of machine tool fault diagnosis with a large number of related characteristics and monitoring blind spots. Therefore, the fault diagnosis of machine tools inevitably requires human participation. For machine tools with a wide distribution area, most of the fault knowledge comes from machine tool design and manufacturing enterprises and users. Therefore, the knowledge of fault diagnosis has the characteristics of dispersion. In the process of fault diagnosis of a certain machine tool, the fault feature analysis must rely on relevant theory and other diagnostic history experience as a reference. Therefore, the integration of human-machine synergy knowledge, theoretical knowledge and maintenance and maintenance experience knowledge is of great significance for the fault diagnosis of machine tools. In the process of using fault diagnosis knowledge, with the improvement of machine tools and the improvement of diagnostic techniques, the content and structure of its knowledge are constantly being improved.

Knowledge of complex equipment fault diagnosis includes design knowledge, manufacturing knowledge, operational knowledge, etc., and there is still a lot of knowledge that is not clear whether it is related. There are differences in the characteristics and expressions of each knowledge. Therefore, constructing a multi-dimensional knowledge representation method that is compatible with basic knowledge, supporting knowledge, supporting algorithm knowledge, and process knowledge is one of the important issues to be considered in the next step.

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