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Intelligent fault prediction system based on internet of things

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ABSTRACT

Fault prediction is the key technology to ensure the safe operation of large equipment. Based on the investigation of current and developing research of fault prediction, an intelligent fault prediction system based on internet of things is proposed in this paper. The system is used for key mechanical equipment groups, and aims at improving the working efficiency and the intelligent level of fault prediction. First the characteristics of the system are analyzed, and then the four-layer functional architecture of the system is designed to realize comprehensive condition monitoring, reliable information transmission and computer intelligent information processing for fault prediction. And three main difficulties faced in the system are discussed. The fault prediction system based on internet of things can provide technical means to achieve scientific predictive maintenance for large key mechanical equipment groups.

1. Introduction

Safety of key equipment groups has significant impact on production and human resources as well as environment. Key mechanical equipment groups such as high speed compressors and turbines are the core equipment in industrial production. Once fault happens, the production would be interrupted, and enormous loss of production and human resources as well as environment would be caused. Therefore, how to guarantee the safe operation of the key equipment groups is an important problem faced in the production.

Work has been done in three stages to ensure key mechanical equipment operating securely and reliably, along with the development of computer applications. The first stage is to monitor the operating of the equipment. The second stage is to diagnose fault, which is usually conducted when malfunction occurs. And the third stage is to predict fault, which is usually carried out before malfunction. Fault prediction can predict the trend of condition development of equipment running earlier than fault diagnosis, and it is one key technology to ensure the safe operation of large key equipment.

The related work about fault prediction has been done in many countries [1,2]. The MFDT (Machinery Failure Prevention Technology) in the USA had founded the diagnosis and prediction group. Bently Nevada has developed DM series system to make online fault diagnosis for equipments. And many other fault prediction systems, such as Vibro-Turbo series in Vibro-Meter(Swiss) and CSI series in Canada and HMH series in Japan, have been developed. In China much work has been done in universities and companies. However most of the related work is focused on the fault diagnosis, mainly about the types and degree of the fault; few studies have been done on fault prediction. Meanwhile the researched objects are mostly one or one type equipments; key equipment groups as a whole are less concerned.

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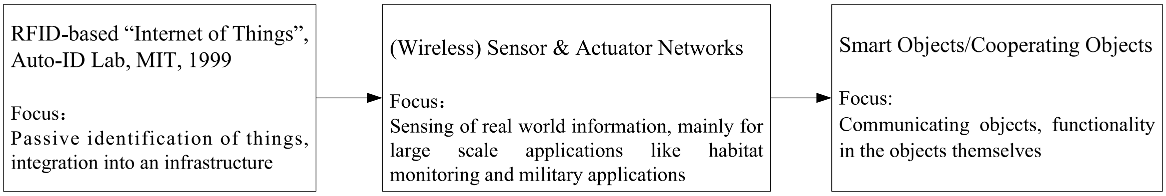

Fig. 1. Evolution of the internet of things.

In order to improve the working efficiency and intelligent level of fault prediction, this paper treats the key mechanical equipment groups as an organic whole, and introduces the technology of internet of things to design an intelligent fault prediction system based on internet of things to ensure safe operation for key mechanical equipment groups.

2. Analysis of fault prediction system based on internet of things

Fault prediction system based on internet of things is a new way to ensure the safe operation for key mechanical equipment groups. It combines the advantages of the internet of things and many other technologies such as computer applications and so on to make fault prediction. And it can be considered as the new developing mode of equipment fault monitoring, diagnosis and prediction.

2.1. Internet of things

The internet of things is regarded as the third wave of information industry after the computer and the internet and mobile communication network [3,4]. The concept was coined by Kevin Ashton of Massachusetts Institute of Technology (MIT) in 1999. The internet of things has experienced three main evolution stages of RFID-based "internet of things" and (wireless) sensor and actuator network and smart objects/cooperating objects. The evolution of the internet of things and the correlative focus are shown in Fig. 1.

The internet of things combines sensor technology, communication network, internet technology and intelligent computing technology and so on, to achieve sensor and reliable convey and intelligent processing [5]. And it has three characteristics as follows. One is comprehensive perception, that is, the real-time collection of the things is dynamically achieved by all kinds of available perception means. Another is reliable transmitting, that is, the perception information is reliably transmitted by all sorts of computer or network and the Internet. And the other is intelligent processing, that is, intelligent computation such as cloud computing could be used for analysis to the massive information, so as to implement intelligent control of the things.

In recent years, the internet of things has developed rapidly and globally due to increasing government and enterprise investment. And it is mainly used in materials flow supply, traffic transportation, social networking, identification recognition and so on. However it is less used in large scale monitoring, diagnosis and prediction for equipment running [6,7].

2.2. Characteristics of the fault prediction system based on internet of things

The equipment monitoring, diagnosis and prediction system has experienced three modes, namely (1) offline mode; (2) single equipment online mode; (3) distributed online mode. In offline mode, the operating information of the equipment is monitored by various sensors, and transferred to computer through data acquisition device, and then the fault diagnosis or the fault prediction is carried out. This mode is economic and convenient but only applicable for regular detection. In single equipment online mode, a set of condition monitoring and fault analysis system is installed for one or one type of equipment. This mode enjoys the advantages such as good real-time performance and high reliability, but it is not economic and hard to share information among different monitoring and diagnosis systems. The distributed online mode can overcome the bad economic performance and information sharing difficulties to some extent, but it is limited by territorial restriction and fails to carry out remote fault prediction.

Fault prediction system based on internet of things is developing on the three modes, and it can break through original frame of traditional monitoring and fault diagnosis. The combination of internet of things and fault prediction can make full use of more technology supports and commonly share more information to carry out flexible remote fault prediction, thus improve the working efficiency and the intelligent level of fault prediction. In this mode the network evolved into a connecting network of diverse devices (concluding equipment groups and various monitoring instruments) and humans (equipment users, equipment managing persons and fault prediction experts). The system can make all connected, all communicating and sharing information to realize comprehensive condition monitoring, reliable transmission and intelligent fault prediction processing of the fault information from the mechanical equipment groups [8].

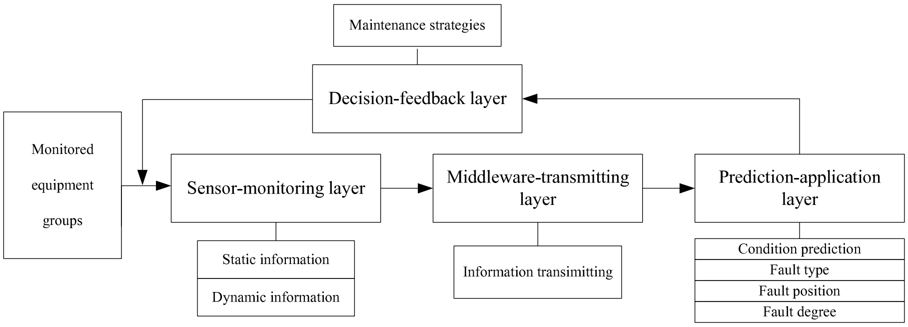

Fig. 2. Four-layer functional structure of the fault prediction system based on internet of things.

3. Design of functional structure

The fault prediction system based on internet of things is designed to be an interconnecting network to predict the fault for key mechanical equipment groups. Its functional structure is composed of four layers, namely sensor-monitoring layer, middleware-transmitting layer, prediction-application layer and decision-feedback layer as shown in Fig. 2.

The system is intelligent and its intelligence of the system is represented in all interconnecting of equipment, monitoring sensor network, fault prediction experts and equipment users or management persons together, to make an intelligent loop of equipment monitoring, prediction and maintenance. The intelligence is also represented in performing computer intelligent information processing like intelligent computation to analyze the standardized information collected in the prediction-application layer, in order to implement intelligent predictive maintenance for equipment groups.

3.1. Sensor-monitoring layer

The sensor-monitoring layer is the basis of the system, and it is mainly for the monitoring of the equipment groups with the static and dynamic information of equipments collected. It is composed of the monitored equipment groups, data collection devices and data collection terminals as shown in Fig. 3.

In this layer the static information such as the name, type and material of the equipments are collected by radio frequency identification (FRID) and stored into the labels directly. FRID can identify the equipment groups automatically and has the advantages of high efficiency managements and reduced cost. The dynamic information such as vibration, velocity and pressure, which can reflect the actual operating condition of the key mechanical equipment groups, are acquired by the various kinds of sensors and stored in the data collection terminals of this layer.

The sensor-monitoring layer can process simultaneously up to 4 channels key phase signals, 24 channels vibration signals, 12 channels static analogy signals, as well as up to 256 process variable data. The signals such as key phase/speed signal, shaft and bearing vibrations, axial displacement, differential expansion and eccentricity come from buffer output as BENTLY3300/3500, ENTEK and PHILIP field monitoring system directly, or from various sensors via special port. In the acquired dynamic information the vibration characteristics can reflect the running condition of the mechanical group systems more directly, rapidly and accurately than the other condition characteristics. The various types of information are standardized, so as to suit the information transmission needs of the internet of things.

3.2. Middleware-transmitting layer

Middleware-transmitting layer is an important link part, which connects the sensor-monitoring layer with the prediction-application layer. The layer is mainly composed of middleware server of the internet of things and the multi-protocol heterogeneous interfaces to transmit various kinds of information as shown in Fig. 4.

In this layer the standardized information can be transmitted from the sensor-monitoring layer to the prediction-application layer by means of wireless or GPRS and so on under the uniform standard protocol, when it is needed by remote requirements among client computers, application servers and database servers.

3.3. Prediction-application layer

Prediction-application layer is the core application layer, which consists of remote expert teams, individual remote expert and data warehouse and so on (see in Fig. 5).

In this layer various kinds of operation information about equipment groups are processed intelligently. Computer intelligent interconnecting information fusion module is built to process the information intelligently and it mainly consists of input interface, output interface and intelligent information processing part. Input interface includes three groups of input information, which are information from mechanical kinetics model, data-driven trend prediction model and revision of

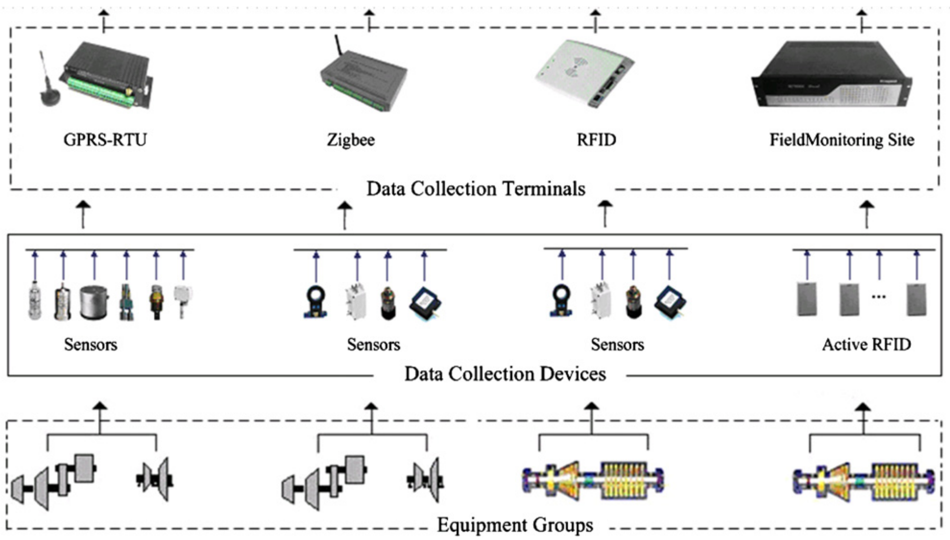

Fig. 3. Composition of sensor-monitoring layer.

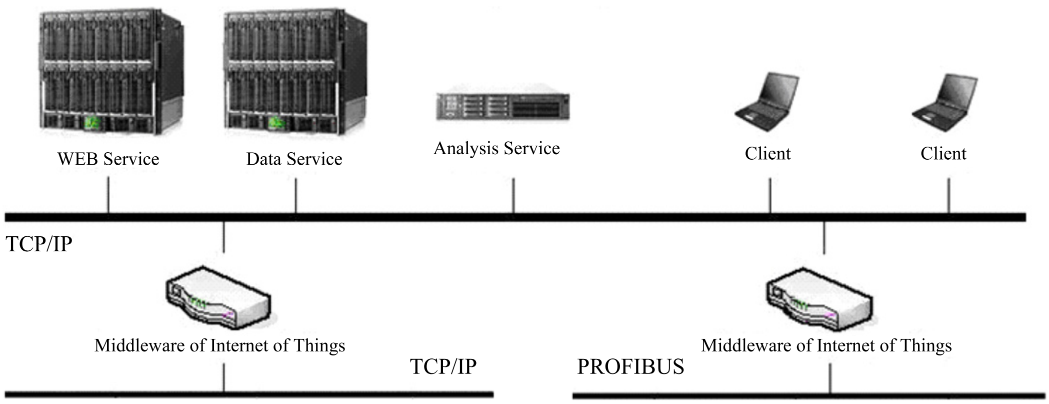

Fig. 4. Composition of middleware-transmitting layer.

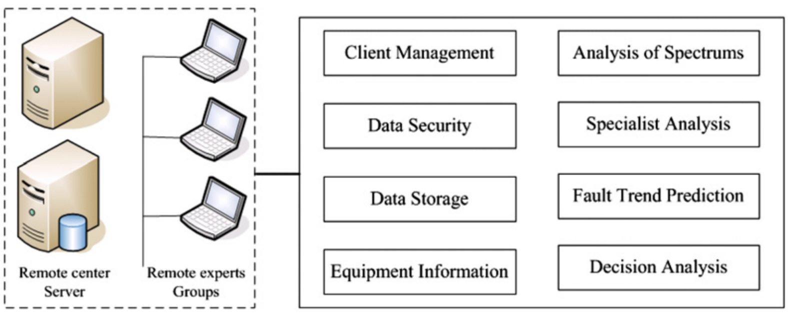

Fig. 5. Composition of prediction-application layer.

fault prediction. The output interface includes two groups of output information, which are information from fault prediction and current condition. Intelligent information processing part includes multiple DSP system and computer intelligent processing algorithms. The algorithms include data mining algorithms, dynamic adaptive algorithms, feature mapping algorithms, information fusion and fault prediction algorithms. For example prediction of vibration characteristics based on neural network is to train the network on basis of the sample data. M-step prediction uses the $N(N \geq 1)$ adjacent sample data to predict the future $M(M \geq 1)$ data. One division method of the sample data for prediction is shown in Table 1.

Table 1
Sample data division method.

N inputs	M outputs
$X_1, X_2, \ldots, X_N$	$X_{N+1}, X_{N+2}, \ldots, X_{N+M}$
$X_2, X_3, \ldots, X_{N+1}$	$X_{N+2}, X_{N+3}, \ldots, X_{N+M+1}$
…	…
$X_K, X_{K+1}, \ldots, X_{N+K+1}$	$X_{N+K}, X_{N+K+1}, \ldots, X_{N+M+K-1}$

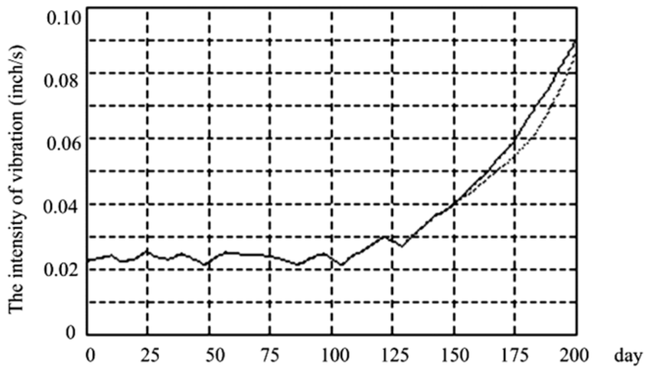

Fig. 6. Prediction based on neural network for the flue gas turbine groups.

Making flue gas turbine group as an application object, the intensity of vibration prediction result based on the neural network is shown as a dotted line in Fig. 6. As each predicting step of the method undergoes learning how to operate itself, the prediction accuracy is high.

In the layer various kinds of computer processing algorithms are used to conduct fault prediction according to different needs. Unfortunately, there is not a unified classification for fault prediction approaches now. In accordance with the application range of theory and technology widely adopted in actual study, the algorithms are roughly classified into three kinds, i.e. model-based approaches, knowledge-based and data-based algorithms [9–11]. Model-based kind of algorithms can touch object characteristics in-depth on the premise that mathematical model of the studied objects is known. However, it is hard to set up exact mathematic models for complex dynamic systems in engineering field, so actual application and effect of these kind of approaches is limited largely. Knowledge-based kind does not require exact mathematical models, and its greatest advantage is to make use of expert knowledge and experience in related fields. The representative applications are expert system and fuzzy logic. But it is only fit for qualitative reasoning instead of quantitative calculation, so the actual application is limited in some extent. In process of actual fault prediction, it is uneconomical or even impossible to establish mathematical models for operating conditions of complex equipment. Meanwhile, expert experience and knowledge in the fields cannot be expressed effectively. However, data-based fault prediction approaches are based on data monitored, and the prediction can be carried out by mining implicit information to avoid the shortcoming of model-based approaches and knowledge-based approaches. This kind has become applicable for fault prediction. The representatives are neural network, hidden Markov model etc. Nevertheless, in actual applications, it is hard to obtain typical data. In addition, it also brings processing difficulties for uncertainty and incompleteness of the data obtained.

3.4. Decision-feedback layer

Decision-feedback layer is actually an output module of the prediction-application layer. Through this layer reference strategies inferred from the prediction-application layer are provided for EAM (enterprise apparatus management). The prediction information gained in the prediction-application layer can reveal the current mechanical equipment operating condition scientifically and effectively at any time and predict how long the future condition of the equipment groups will reach an unacceptable level and should be down for maintenance. Accordingly, the enterprise apparatus managers can conduct scientific predictive maintenance as needed rather than conducting traditional maintenance way at specified intervals, thereby the maintenance way can change from the traditional preventive maintenance up to the advanced condition based maintenance way.

The traditional maintenance way is the preventive maintenance based on time, and it is also called periodic maintenance. The preventive maintenance way is compulsory periodic maintenance replacing the parts at a fixed time with high maintenance costs. Although the cumulative halting down time is long, it still cannot avoid the vicious incidents. The predictive maintenance way is based on condition, and it is also called condition maintenance. The predictive maintenance way is a newly dynamic maintenance way, and it can alter the traditional equipment maintenance way fundamentally. In the new way the maintenance is performed according to the monitored operation condition of the equipment and the fault prediction result. Therefore the overall utilizations of the equipment can be increased, much maintenance cost can be saved, and accordingly the productivity is lifted largely.

4. Discussion of three main difficult points

There are three main difficult points faced in the system and they are discussed as follows.

(1) The combination difficulty of the fault prediction and internet of things.

How to combine the technology of fault prediction and internet of things together closely is one difficult point. Although the internet of things is the extension of internet, the communicating ways used in the internet of things are more complicated than those used in internet. The difficulty can be solved partly by choosing proper wireless sensor network structures, transmission protocols and common standard data interfere. So standards or norms and coding of the communicating protocols are needed to establish further for better combination [12]. Close combination of fault prediction with the internet of things can help to acquire, transmit and make full use of the equipment groups running information to perform effective fault prediction based on the internet of things.

(2) Non-stationary and nonlinear fault prediction difficulties.

Large key equipment groups used in the industrial site are often running with large power and heavy load, and in long process of equipment running disturbance of non-fault factors, such as changes of working condition and load are major non-stationary reasons for fault prediction. As mechanical equipment is a kind of complex nonlinear power system and most faults of the mechanical equipment experience the developing process of occurrence to deterioration, when fault prediction adopts traditional approaches, the nonlinear factors are usually neglected. Consequently, the solutions derived from the traditional linear approaches fall far from fact.

Along with increasing requirements towards prediction accuracy, non-stationary and nonlinear problems have been highlighted and accordingly non-stationary and nonlinear prediction approaches suitable for nonlinear systems are needed to be explored further. For example Hilbert–Huang Transform (HHT) or Wavelet Transform/Wavelet Packet Transform (WT/WPT) or intelligent approaches (like artificial neural network and expert system etc.) are used to solve the difficulties [13,14].

(3) Massive data processing difficulties.

The data acquired from the sensor-monitoring layer are massive. Various kinds of dynamic information are gained in the layer, including vibration value, revolving speed, temperature and pressure and so on. And the data cover the working conditions, load and environmental factors of the equipment groups. How to process the massive data to make effective representation, store, searching and sharing is a very difficult problem faced.

To solve the problem, distributed store and distributed computer processing are needed to develop further. And also dimension reduction algorithms or information fusion methods and so on can be used to extract the lower dimensional information from the massive data or make information fusion to get the actual operation status of the equipment [15–17].

5. Conclusions

The fault prediction system based on internet of things is a new mode to ensure the safe operation for key equipment groups. It can make full use of the internet of things to perform computer intelligent information processing for fault prediction of the key equipment groups. Based on internet of things, condition monitoring and fault diagnosis and fault prediction can be flexibly performed through four-layer functional structure of the system. Moreover, technical means for implementation of scientific predictive maintenance can be provided through the decision-feedback layer for key equipment groups.

The proposed system exerts significant implication on following aspects, such as realizing fault prediction in early stage improving working efficiency and intelligent level of fault prediction, guaranteeing safe operation, saving maintenance fees and improving utilization rate, as well as achieving scientific maintenance and so like. In summary the system can promote the application of the internet of things in equipment safety. And it has a broad application prospect in equipment maintenance.

Acknowledgments

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