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Design and Implementation of Intelligent Fault Diagnosis System for Construction Machinery Supporting Wireless Communication Network

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Abstract: The traditional fault diagnosis(FD) system of construction machinery(CM) is not competent for the task of FD of modern construction equipment because of its own bottleneck. Nowadays, the computer network information technology and wireless communication technology are highly developed, so it is the development trend and trend of mechanical FD technology to design a FD system based on wireless communication network for CM. The FD system in this paper is constructed based on wireless communication network and fuzzy FD method, which is used for FD and maintenance of CM and equipment, and realizes intelligent collection of mechanical fault data in construction site. By testing the performance of the system and the accuracy of the FD model, it shows that the system performance test is good, and the FD rate is over 90%, which can meet the system objectives and requirements.

1. Introduction

There are many important small parts in CM and equipment, and these parts are not very reliable, that is, easy to be damaged. If one of the components is missing, it may cause a lot of faults, and even lead to casualties on the construction site. Therefore, it is necessary to improve the mechanical FD technology to reduce the economic losses caused by the faults and ensure the safety of personnel.

Through the painstaking research of researchers, a relatively complete system has been formed in the application of intelligent computing to develop FD. For example, some scholars have analyzed that the wireless communication network mechanical FD system first needs to accurately collect the vibration signals of key components of mechanical equipment, because all FD methods are based on the original data for processing and analysis, and the key to solving the problem of accurate acquisition of vibration signals is to select high-precision acquisition nodes [1].

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Researchers have been studying FD methods. The support vector machine and genetic algorithm in FD algorithms involve a large number of matrix algorithms, which require too much computation for wireless sensor networks [2]. Fuzzy logic is usually effective in dealing with imprecise problems, which can qualitatively reflect the changes of the monitored objects, but can't accurately reflect the degree of changes. Bayesian probability theory in multi-node decision fusion is often used in FD fusion process, but it will only be effective if every possible result is known [3]. The research on FD technology has achieved good results, and many scholars have verified the related diagnosis algorithms, which also proves that the proposed algorithm can be applied to FD.

Firstly, this paper introduces the fuzzy FD method and system design principle, and intelligently diagnoses mechanical faults by fuzzy logic reasoning when designing the FD system. Then, the system framework and data acquisition module are constructed, and the system test proves that the system can meet the diagnosis and operation requirements. Finally, the realization process of data acquisition is analyzed.

2. FD Methods and System Design Principles

2.1. Fuzzy FD

Because some fault states are fuzzy, mechanical FD can be completed by fuzzy logic reasoning. Fuzzy inference rules are based on the test of key signal parameters, and calculate the value of fault membership degree [4]. To use fuzzy reasoning for FD, it is necessary to establish the following diagnosis model. Assume that X is the set of possible fault phenomena and Y is the set of fault causes.

$$X = \{x_1, x_2, \dots, x_m\} \tag{1}$$

$$Y = \{y_1, y_2, \dots, y_n\} \tag{2}$$

$$R = \begin{Bmatrix} r_{11} r_{12} \cdots r_{1n} \\ r_{21} r_{22} \cdots r_{2n} \\ \cdots \quad \cdots\cdots\cdots \\ r_{m1} r_{m2} \cdots r_{mn} \end{Bmatrix} = (r_{ij})_{m \times n} \tag{3}$$

In the formula, the element xi (i = 1,2, ..., m) represents the phenomena of various possible failures, and the element yi (I = 1,2, ..., n) represents the causes of various possible failures. r_{ij} is the fuzzy matrix of fault phenomena and causes.

2.2. Principles to be Followed in System Design

(1) Normative design principles the design and development process should strictly implement national standards and relevant industry norms, and the management of system information must conform to the regulations of management information system, and the information resources should be utilized according to the format regulations of industry Web system [4].

(2) The principle of reliability design ensures that the designed system has good compatibility, can respond to system emergencies in time and quickly, and has good system stability and data

security to ensure the consistency between the data displayed on the interface and the data in the database. Ensure that the system will not crash and data resources will not be lost in case of emergency [5].

(3) Practical design principle highlights the convenience and simplicity of system design and operation, in which easy operation is the aspect that must be considered when designing software. The usability should be considered as much as possible in system design, so that the menu is concise and the user functions are comprehensive.

(4) Extensibility and open design principles When designing and developing the system, we should think big and make full use of the advanced technological achievements to realize the functions of the system [6].

3. Design of FD System for CM Based on Wireless Communication Network.

3.1. Demand Analysis of FD of CM

In the construction process, a variety of large-scale construction machines are needed to cooperate. The following two kinds of CM FD are introduced.

(1) FD of paver

Paver is a key and core equipment in the CM group, and it is the basic requirement to ensure the normal construction period and the overall benefit of the construction equipment [7]. After analyzing the faults of paver system, it is necessary to diagnose the faults of hydraulic system, electrical system, diesel engine system and centralized lubrication system. In the electrical system, each fault symptom extracted can directly deduce a variety of possible fault causes. However, in other systems, there is usually no one-to-one correspondence between fault phenomena and fault causes, so intelligent diagnosis is needed to complete [8-9].

(2) FD of transfer vehicle

According to the mechanical structure of the transfer vehicle, it is necessary to divide the FD system of the transfer vehicle into five subsystems: power system, running system, working system, hydraulic system and electrical system, and implement FD respectively [10]. Hydraulic system and electrical system are the control and driving parts of the transfer vehicle, which must be part of the power system, driving system and working system. However, for the convenience of classification in FD, the hydraulic system and the electrical system are separated. Each subsystem also contains two kinds of faults. The first kind of fault can directly obtain the corresponding switch value of the transfer vehicle through the fault symptom, so as to diagnose it. However, there is no direct correspondence between the symptom of another kind of fault and the cause of the fault, so it is necessary to carry out intelligent diagnosis according to a series of symptom of each subsystem [11-12].

The FD system of CM mainly includes two sub-expert systems: paver and transfer truck, and the functions of each sub-expert system are realized by the diagnosis system and information management system respectively. The system structure is shown in Figure 1.

Man-machine interface is used for the interaction between the system and users, which supports users to select fault symptoms through a friendly graphical interface, evaluate the diagnosis results, and confirm whether to save this diagnosis as a valid historical record [13].

The inference engine is responsible for acquiring knowledge from the knowledge base, and reasoning and diagnosing faults according to the user input received by the man-machine interface. The inference engine in the system consists of two parts, one part is used for simple rule reasoning in conventional systems, and the other part is used for fuzzy reasoning with fuzzy neural network to complete intelligent FD [14-15].

The interpreter is responsible for establishing the mapping relationship between various fuzzy values and actual semantics, building a bridge for communication between users and expert systems, and submitting diagnosis results and corresponding treatment opinions in a way that users can understand.

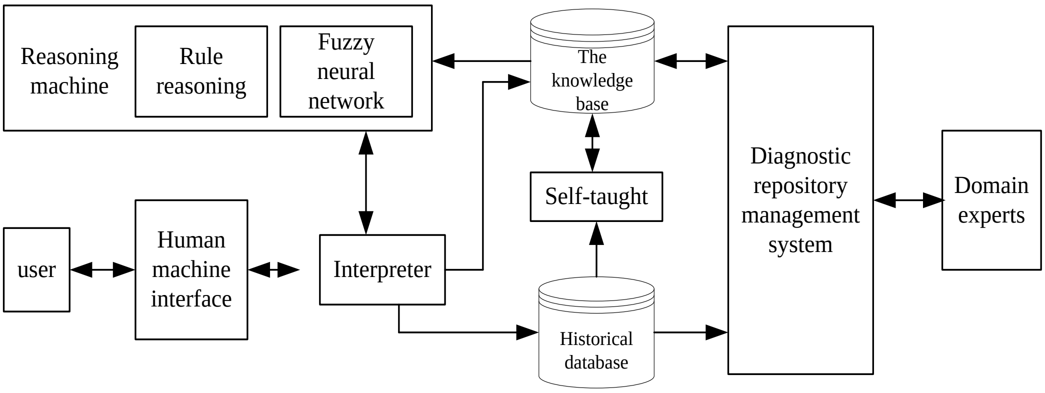

Figure 1. System structure diagram

Knowledge base is the core of the whole expert system. In order to obtain good expansibility, knowledge base is stored in the form of database. Knowledge inventory contains basic information of mechanical system, basic reasoning rules and fuzzy knowledge expressed by fuzzy values [16]. The traditional production system can only express deterministic knowledge, and the fuzzy knowledge in this knowledge base is mainly contained by the fuzzy matrix between fault symptoms and causes in each subsystem.

The historical database stores effective historical FD result data, which contains not only the symptom information when a fault occurs, but also the intermediate data and result data of the whole reasoning process. On the one hand, it can be used to transform into FD samples, which can be provided to the knowledge base for further study and self-improvement. On the other hand, it can provide basic materials for the statistical analysis of historical failures, so that domain experts and engineers can know the time, location, severity, cause of mechanical failures or the frequency of each failure of a subsystem [17-18].

The diagnosis information base management system is an information management system specially customized for the FD database. Through this system, domain experts can add, delete, change and query the contents of the database.

3.2. Design of Data Information Acquisition Terminal

Sensor nodes needed to set up a network in a wireless network mechanical failure system include terminal nodes and gateway nodes. Each terminal adopts dual-core architecture, and uses two independent processing and control cores to control the acquisition module and wireless module respectively, so as to give full play to the advantages of dual processors and reduce the burden of the acquisition module processor. The gateway only forwards data commands, so the task is relatively simple, and it is directly connected with the upper computer terminal through serial port without considering the energy problem. The main job of the system information acquisition terminal in the mechanical FD system is to realize the real-time transmission of the fault information of CM based on the wireless communication network. At the same time, as the wireless network is mainly composed of mobile devices, the devices are loosely coupled with the system, so it is designed as an independent subsystem, as shown in Figure 2. Through the wireless local area network, the message response mechanism is adopted to control the flow, and the message server is the center, and the system data acquisition terminal is the auxiliary system structure.

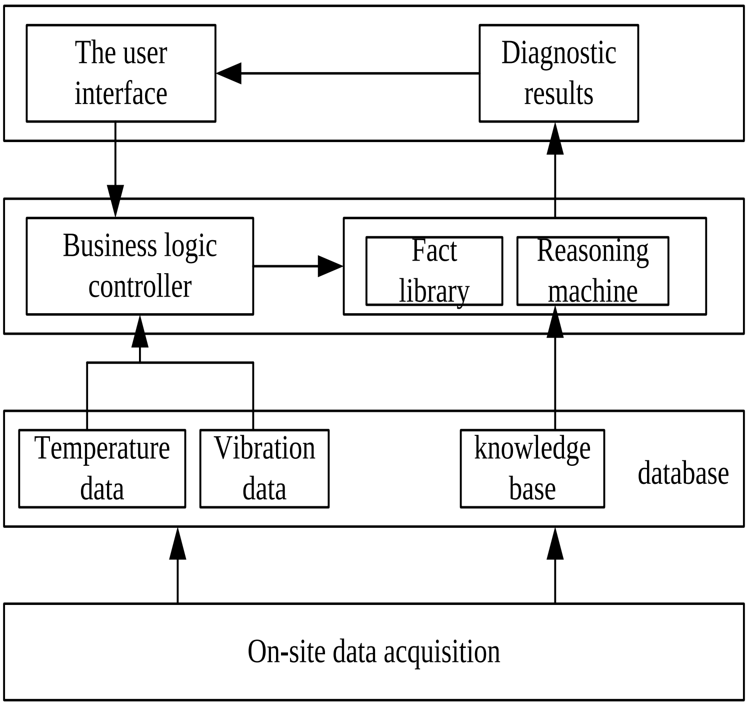

Figure 2. Data acquisition system

4. System Testing and Implementation

4.1. Accuracy Test of FD Model

In order to make the developed FD system have better usability, the FD model in this system must have higher accuracy. Therefore, it is necessary to test the accuracy of the diagnosis model. Therefore, 100 pieces of normal and fault data are selected from the data set as the test set, and the FD model is tested for three times. The diagnostic results obtained and the accuracy test of the FD model are shown in Table 1.

Table 1. Accuracy test of FD model

	Number of test set data	Normal quantity	Number of faults	Accuracy (%)
A	100	34	66	93.67%
B	100	30	70	95.45%
C	100	32	68	92.98%

According to Table 1 and Figure 3, the test data set A contains 34 normal data and 66 fault data, and the FD accuracy rate is 93.67%. There are 30 normal data and 70 fault data in data set B, respectively, and the FD accuracy rate is 95.45%. Data set C contains 32 normal data and 68 fault data respectively, and the FD accuracy rate is 92.98%. Generally speaking, the FD accuracy of intelligent computing FD model is over 90%, which meets the design standard and has a high accuracy.

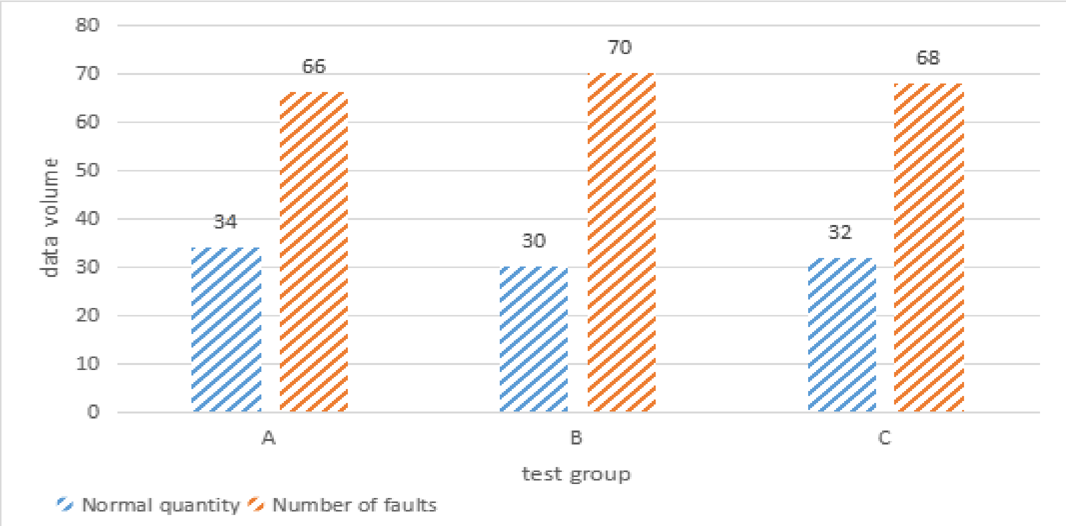

Figure 3. Distribution of normal data and fault data

4.2. System Performance Test

Test the performance of the system, such as the time it takes to process data, the average occupancy rate of CPU and the average occupancy rate of memory. The data acquisition and FD model of the FD system of CM are trained with 500 and 1000 data, and the test results are shown in Table 2.

Table 2. Performance test results

	Data volume	Processing all time (s)	Average CPU usage (%)	Average memory usage (%)
Data acquisition	500	21	24.68	27.94
Data acquisition	1000	35	32.14	28.33
Diagnostic model	500	17	24.32	35.67
Diagnostic model	1000	26	31.56	42.91

According to Table 2, no matter whether the amount of test data is 500 or 1000, the FD model of intelligent computing can meet the user's demand for the system in terms of the time taken by the FD system to process data, the average occupancy rate of CPU and the average occupancy rate of memory.

4.2. Implementation of Data Acquisition

The data acquisition in the system mainly realizes the acquisition of vibration information, temperature information and rotational speed information of on-site construction equipment. The vibration information of the equipment is acquired by NI acceleration sensor and the corresponding data acquisition module. After the acquired vibration data is processed by the Labview program of the upper computer, part of the data is stored in the Oracle database, part of the data is stored locally in the form of waveform files, and part of the data is delivered to the Labview WebService for real-time Web publishing. The reason for this is that the information of vibration data of equipment is relatively large, and the database can't bear the load of such a large amount of data, so it can only adopt some storage strategies. However, in order to know the vibration information of equipment in real time, it is necessary to publish the real-time data on the Web. In this way, we can continuously monitor the operation status of the equipment on the construction site and trace the historical information of the equipment, and also reduce the load of the database, thus improving the operation efficiency of the system. The temperature of the equipment is obtained by wireless sensor network, and the rotating speed is read in real time by OPC technology. As the amount of information of these data is relatively small, they can all be stored in the data. At the same time of data storage, these data will also be published on the Web so that users can know the temperature and speed information of the equipment in real time.

5. Conclusion

Intelligent FD technology can effectively improve the reliability of diagnosis system, the accuracy of system detection and the convenience of system maintenance on the basis of traditional diagnosis technology. This paper mainly designs the FD system of CM combined with wireless communication network technology, and tests and realizes the FD system. Through the test of the system, the problems existing in the system can be found as early as possible, thus avoiding errors when the system is put into use. According to the test results of the system, the system performance and the accuracy of FD have achieved the expected effect of the system.

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Data Availability

Data sharing is not applicable to this article as no new data were created or analysed in this study.

Conflict of Interest

The author states that this article has no conflict of interest.

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