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Servitisation of Fault Diagnosis for Mechanical Equipment in Cloud Manufacturing

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Abstract—**Faults in mechanical equipment could cause breakdown of time-critical production systems, which is very expensive in terms of production losses and re-commissioning costs. In cloud manufacturing, the scattered distribution of mechanical equipment and fault diagnosis resources, such as experts and specialist instruments, etc., could hinder the development of fault diagnosis systems. The idea of resource servitisation, aimed at resource sharing and collaboration, will lead fault diagnosis systems toward integration, low cost and high efficiency. This paper focuses on the servitisation of fault diagnosis for mechanical equipment in cloud manufacturing. A new service-oriented fault diagnosis system framework for mechanical equipment is proposed, together with a new servitisation method of fault diagnosis for mechanical equipment. Moreover, enabling technologies, e.g. XML, Web Services Definition Language (WSDL), Axis2, are also analysed. Finally, a prototype system is presented that demonstrates the feasibility and effectiveness of the developed architecture and servitisation method in a cloud manufacturing environment.**

Keywords—fault diagnosis; servitisation; fault diagnosis; cloud manufacturing.

I. INTRODUCTION

With the development of information technology and computer networks, globalised competition and cooperation is a trend in manufacturing, which brings difficulties to equipment maintenance. How to provide enterprises with a convenient and rapid equipment fault diagnosis service to respond swiftly to customers' requirements so as to improve the competitiveness of enterprises has become a significant issue in manufacturing area.

Fault diagnosis [1, 2] aiming to avoid the occurrence of faults, especially major accidents, can extend repair cycles and improve production efficiency. Mechanical equipment, as the most important manufacturing resource in an industrial process, must operate continuously, because breakdowns are very expensive in terms of production losses and re-commissioning costs. Hence, effective fault diagnosis becomes crucial for reliable operations. Cloud manufacturing [3, 4] is a service-oriented, requirements-driven, intelligent, agile and networked new manufacturing model aimed at realising the high degree of sharing, on-demand use and dynamic collaboration of manufacturing resources, so as to improve the utilisation efficiency of manufacturing resources. In order to cater for the requirements of a cloud manufacturing environment, a new framework for mechanical equipment fault diagnosis should be designed to fit the environment.

In the past two decades, many fault diagnosis systems have been developed and applied, including on-site single machine systems, distributed systems based on LAN [5] and remote fault diagnosis systems [6-9] based on the Internet. Previously, mechanical equipment performance states were measured and diagnosed by both visual inspection and manual maintenance which mainly relied on professional experience and knowledge of individual experts. With the emergence of ICT (Information and Communication Technology), such as new sensor technologies, Internet of Things, fault diagnosis systems have moved towards greater flexibility, servitisation and integration. In [10], Deng described a remote fault diagnosis system with Internet, LAN, PSTN, GSM communication networks, which connect all participants in the fault diagnosis process. In [11], an intelligent alarm and fault diagnosis system for transmission equipment in a smart substation is introduced, adopting a multi-agent structure. In [12], a help-desk system was designed to support online machine fault diagnosis over the Internet, which combines neural network and rule-based reasoning to analyse and mine customer service databases. Nowadays, data-driven diagnosis, as one of the most fruitful research areas, has wide applications in system diagnosis [13]. In [14], Yin proposed a data-driven fault detection approach in a wind turbine system. In [15], a robust data-driven scheme was successfully used in an antilock braking system diagnosis, in which a sensor fault and four parametric faults were detected and isolated. In [16], Yin researched the data-driven approach in the process industry, and successfully applied it on an industrial benchmark fed-batch penicillin production process.

These fault diagnosis systems have realised remote monitoring and diagnosis with sensors and communication devices. However, current fault diagnosis systems exist as islands, which means each diagnosis system is independent of the others and reduces efficiency in information exchanging and sharing. In order to improve system performance in terms of resource sharing and cross-platform interoperability, and eliminate information island, some international standards and new advanced technologies, such as XML, WSDL [17], OWL-S (Ontology Web Language for Services) [18], SOA (Service Oriented Architecture) [19], etc., have been developed. In a cloud manufacturing environment, various kinds of resources are considered as services, such as monitoring services, design services, fault diagnosis services, etc. The drawbacks in previous systems can be improved through the cloud manufacturing framework.

This servitisation of resources promotes resource sharing and integration. However, the wide distribution of manufacturing equipment and fault diagnosis resources causes high maintenance costs and low efficiency of fault discovering and solving. Servitisation provides a valid way to resolve conflict and increase the efficiency of fault diagnosis system in terms of knowledge sharing and maintenance cost reduction. In this paper, we propose a novel mechanical equipment fault diagnosis system in cloud manufacturing by adopting cloud manufacturing ideas and SOA technologies and diagnostic skills.

The remainder of the paper is organised as follows. Section 2 introduces the architecture of a mechanical fault diagnosis system. Fault diagnostic methods and servitisation processes are described in section 3. Section 4 discusses the prototype system and its implementation. Finally, we conclude the paper in section 5.

II. SYSTEM FRAMEWORK

The system aims to realise mutual communication, cross-platform operation and collaboration of service objects and establish a union fault diagnosis service platform for fault diagnosis participators. Manufacturers, experts and equipment users are connected together by the platform. The framework of the fault diagnosis system is shown in Fig. 1. In the system, service providers, including manufactures, experts and research institutes, register their fault diagnosis services on the platform, and service users can search diagnosis services. The system is mainly divided into three parts, monitoring and data collection, heterogeneous network convergence and cloud service platform.

Condition monitoring and data collection of the mechanical equipment is an essential step for the fault diagnosis system. In a general factory, a local monitoring system is deployed to collect the mechanical equipment information automatically, including static and dynamic parts. The static information, such as model, number, manufacturer, etc., is monitored by RFID readers [20]. The devices are also used to collect the task information automatically, such as production quantity, which can show the manufacturing capability and further judge the machine works normally or not. In addition, the dynamic part including working parameters, load status and ambient environment information can be acquired by various advanced sensors and embedded devices, such as Fiber Bragg Grating (FBG) sensor [21], laser measurement device [22,23] and embedded data collection equipment [24], etc.

As the workshop environment become more and more complex, such as electromagnetic interference, noisy and space limitation, the transmission of monitored data with real-time and reliability is an issue. In the system, we adopt different communication means to transfer diverse data. For example, the RFID readers and FBG demodulator are connected with internet, while the temperature and humidity sensors deployed in different places are communicated by wireless models. Hence, different networks are integrated based on the heterogeneous network convergence technology to send the monitored data.

Most factories have their own maintenance departments and engineers, which can deal with emergencies according to the monitored data and their experience. However, if the fault is too complex to solve for the local engineers, they can get help from the cloud service platform for mechanical equipment fault diagnosis. In the platform, fault diagnosis methods are encapsulated into services provided by machine manufacturers and related experts. Fault diagnosis services are registered in the platform and users can search the services with webservice descriptions and matching rules stored in the rule base. In addition, storage management involves a database, knowledge base and services base. The database is designed to store all the data of the system, including the monitoring data, user information and services provider information. The knowledge base includes knowledge for fault diagnosis, such as diagnosis process, fault base, and diagnosis methods. The services registered in the platform will be stored in the services base. As the data stored in the platform is massive and heterogeneous, the data storage system is developed based on the Hadoop, a distributed data storage and processing system. Through the platform, each participant will communicate with webservice, which can promote resource sharing and organisation.

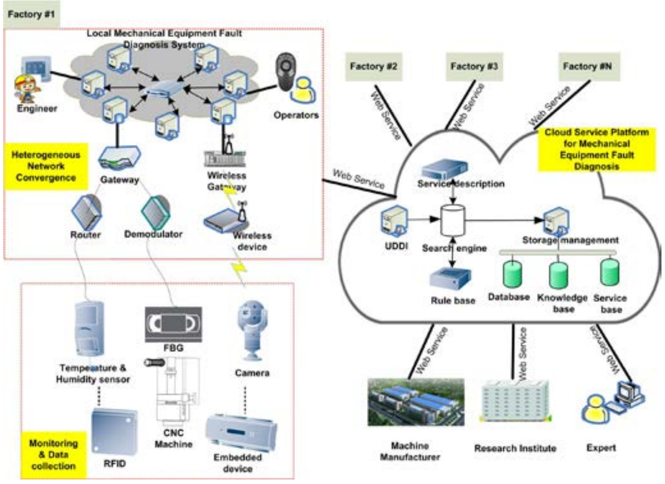


Fig. 1. System framework

III. FAULT DIAGNOSIS SERVITISATION IN CLOUD MANUFACTURING

In this section, we briefly review the current fault diagnosis methods and discuss the main methods that we have used in our machine equipment diagnosis system, and then the servitisation process of diagnosis methods is described in detail.

A. *Fault diagnosis methods*

Fault diagnosis methods have been divided into three classes by Frank [25], namely, analytical model-based methods, signal processing-based methods and knowledge-based methods. Analytical model-based methods can be applied in systems with enough sensors and sufficient information. However, in a large and complex equipment system, model-based analysis methods cannot obtain detailed information of complex mechanistic models.

Intelligent methods such as neural networks, fuzzy logic and genetic algorithms have made great achievements in theory, but how to apply them in practice needs further study. We will focus on signal processing-based methods in this section, which are mature in technology and have been widely used in fault diagnosis in different areas. Signal processing-based methods utilise a variety of signal analysis techniques to extract the fault related signal characteristic of time and frequency domain including spectrum analysis methods and time-frequency analysis methods. Some of the common signal processing methods based on time-frequency analysis include Wavelet transform (WT), Short-time Fourier transform (STFT), Wigner Ville Distribution (WVD), Hilbert Huang Transform (HHT).

B. *Servitisation for fault diagnosis in cloud manufacturing*

Traditional fault diagnosis resources, such as domain knowledge, fault diagnosis methods, signal processing algorithms and diagnosis experience are adopted separately. In order to achieve the fault diagnosis resources sharing in the cloud service platform, servitisation of fault diagnosis resource is a necessary part for services integration. As shown in the Fig.2, the process of servitisation consists of three parts, fault diagnosis resource, virtualisation and servillisation.

As traditional fault diagnosis resources are different in terms of description methods and storage format, description specification is the first step, including integrity, adaptation and extensibility. Then, models and templates are developed to describe each fault diagnosis, which will be used in description of the same fault diagnosis resources. The next step is describing the models based on various description languages, such XML, UML, RDF and OWL, promoting the unified format of models. Creating a mapping mechanism, including the relationship between the fault diagnosis resource and the virtual fault diagnosis service, is the final step of virtualisation of fault diagnosis resources. In a general fault diagnosis system, there are three main mapping modes, point-to-point, single point to multi-point and multi-point to single point. For example, a classic signal processing algorithm can be adopted in various fault diagnosis process. However, in cloud manufacturing, the service mode focuses on multi-point to multi-point mapping. So the mode should be added to the mapping mechanism of virtualisation.

Servitisation of the fault diagnosis resource aims to realise the fault diagnosis services sharing, which will improve the performance of machine fault diagnosis a lot. Three steps will be taken to achieve the goal. The first one is the service description based on the webservice definition language, which defines the interfaces of service and help the service user invoke the service. Then the service will be encapsulated based on Axis2 or other technologies. The last step is service releasing and registration in the cloud platform for searching and invoking by service users.

Through the servitisation of fault diagnosis, the resources including expert domain knowledge, signal processing algorithms and diagnosis methods can be considered as services. Like other manufacturing services, fault diagnosis services have characteristics of on-demand use, high flexibility and rapid response, and can circulate in the cloud manufacturing environment. The user can search and integrate the fault diagnosis services provided by others to correct the fault on the machine.

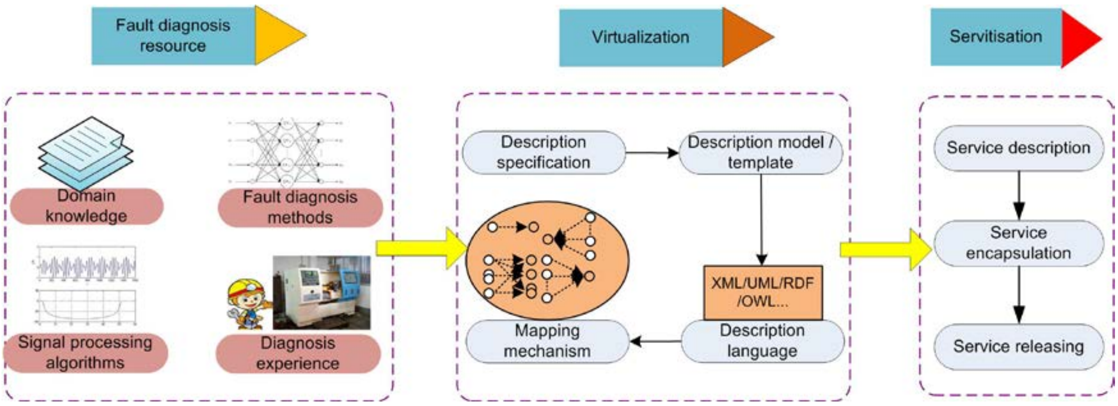
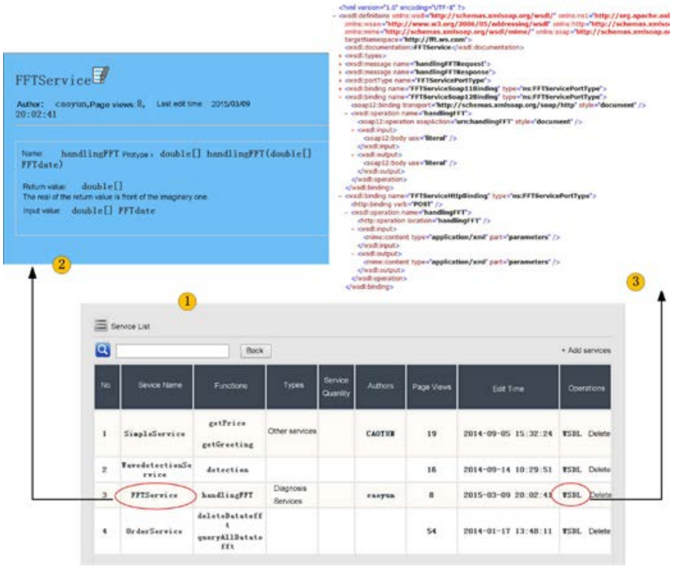


Fig. 2. Fault diagnostic methods virtualisation and servitisation

IV. PROTOTYPE SYSTEM AND ITS IMPLEMENTATION

According to the system framework discussed above, a prototype system is designed base on the SSH (Struts+Spring+Hibernate) structure and Axis2 technology. The main page of the cloud service platform provide interface for service provider to register their fault diagnostic services. For example, FFT (Fast Fourier Transform), as a classic signal process algorithm, is usually used in the fault diagnosis area. The service provider can encapsulate FFT into a service through the platform. The users can search the service list and get the service through the matching rules.

Fig.3 shows the service management pages, including three parts. 1) The main page provides the search interface for services, which can be used to find appropriate ones through services name, type and providers. 2) If a user chooses a diagnosis services, for example, FFT service, then he can get a short service description through clicking the service name. The description briefly introduces the FFTService functions, main function prototype, containing input and output parameters. 3) Further service information described in WSDL can be acquired through operation column. Then the users can choose services with the detailed description information.



FFTService

Author: caoyun,Page views: 8, Last edit time: 2015/03/09 20:02:41

Name: handlingFFT Protype: double[] handlingFFT(double[] FFTdate)

Return value: double[]
The real of the return value is front of the imaginary one

Input value: double[] FFTdate

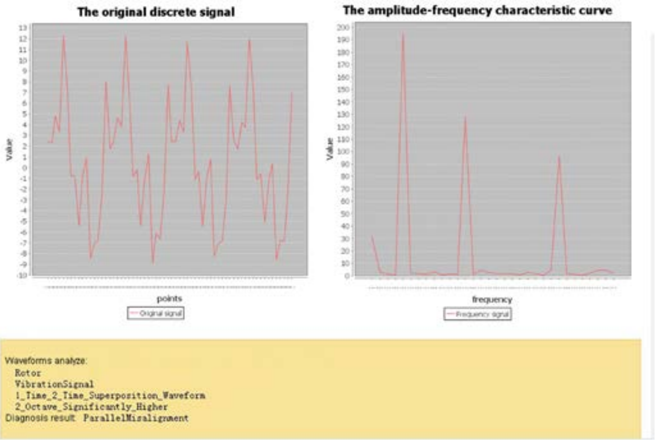
```
<?xml version="1.0" encoding="UTF-8" ?>
- <wsdl:definitions xmlns:wsdl="http://schemas.xmlsoap.org/wsdl/" xmlns:ns1="http://org.apache.axi
    xmlns:wsaw="http://www.w3.org/2006/05/addressing/wsdl" xmlns:http="http://schemas.xmlso
    xmlns:mime="http://schemas.xmlsoap.org/wsdl/mime/" xmlns:soap="http://schemas.xmlsoap.o
    targetNamespace="http://fft.ws.com">
    <wsdl:documentation>FFTService</wsdl:documentation>
+ <wsdl:types>
+ <wsdl:message name="handlingFFTRequest">
+ <wsdl:message name="handlingFFTResponse">
+ <wsdl:portType name="FFTServicePortType">
+ <wsdl:binding name="FFTServiceSoap11Binding" type="ns:FFTServicePortType">
- <wsdl:binding name="FFTServiceSoap12Binding" type="ns:FFTServicePortType">
    <soap12:binding transport="http://schemas.xmlsoap.org/soap/http" style="document" />
  - <wsdl:operation name="handlingFFT">
      <soap12:operation soapAction="urn:handlingFFT" style="document" />
    - <wsdl:input>
        <soap12:body use="literal" />
      </wsdl:input>
    - <wsdl:output>
        <soap12:body use="literal" />
      </wsdl:output>
    </wsdl:operation>
  </wsdl:binding>
- <wsdl:binding name="FFTServiceHttpBinding" type="ns:FFTServicePortType">
    <http:binding verb="POST" />
  - <wsdl:operation name="handlingFFT">
      <http:operation location="handlingFFT" />
    - <wsdl:input>
        <mime:content type="application/xml" part="parameters" />
      </wsdl:input>
    - <wsdl:output>
        <mime:content type="application/xml" part="parameters" />
      </wsdl:output>
    </wsdl:operation>
  </wsdl:binding>
```

No	Sevice Name	Functions	Types	Service Quantity	Authors	Page Views	Edit Time	Operations
1	SimpleService	getPrice getGreeting	Other services		CAOYUN	19	2014-09-05 15:32:24	WSDL Delete
2	WavedetectionService	detection				16	2014-09-14 10:29:51	WSDL Delete
3	FFTService	handlingFFT	Diagnosis Services		caoyun	8	2015-03-09 20:02:41	WSDL Delete
4	OrderService	deleteDatateff t queryAllDatate fft				54	2014-01-17 13:48:11	WSDL Delete

Fig. 3. Description of fault diagnostic service

When users choose the service, they can activate it through the service description. Fig.4 shows a complete fault diagnosis process based on the prototype system. Firstly, the local fault diagnosis platform collected the rotor vibration data of a machine tool. Then an engineer called a FFT service with the collected data. Finally, the converted waveform based on the original data was sent to the local platform, which can help the engineer analyse the working condition of the machine.

Though the demonstration shows a simple FFT service, other fault diagnosis methods can be invoked through the platform. In the same way, fault diagnosis knowledge and rules can be integrated and shared as well, which will greatly improve the fault diagnosis performance.



Waveforms analyze:
Rotor
VibrationSignal
1_Time_2_Time_Superposition_Waveform
2_Octave_Significantly_Higher
Diagnosis result: ParallelMisalignment

Fig. 4. FFT service demo

V. CONCLUSION

Effective fault diagnosis of mechanical equipment helps maintain continuity of manufacturing. In cloud manufacturing, resources, such as machines, software, and people, are considered services for sharing and integration. In the same way, fault diagnosis resources can be encapsulated into services to enhance the performance of fault diagnosis systems of mechanical equipment through knowledge sharing and maintenance cost reduction. In this paper, we introduced a new system framework for equipment mechanical fault diagnosis. Compared to traditional fault diagnostic systems, the proposed system has advantages of real-time capability and scalability. Through analysis of fault diagnosis methods, techniques of virtualisation and servitisation for fault diagnosis resources have been proposed. A prototype system has been presented that proves the feasibility of the new framework.

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