Semantic Service Technologies for Industrial Fault Analysis IoT

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Abstract. This paper presents an industrial fault analysis Internet of Things (IoT) system adopting the semantic service paradigm. Industrial vibration fault analysis becomes increasingly useful for economical and safety reasons. The architecture of vibration fault analysis IoT consists of enterprise level, gateway level and endpoint level where various vibration detection services are integrated. Semantic service involves the collection, representation and processing of relevant information of devices and data was developed. Data processing schemes and services are proposed quantifying the criteria of fault evaluation, and the relevant ontology was designed. Testing results show the effectiveness of the proposed approach and system design in increasing the flexibility and accuracy of real-time industrial vibration fault analysis.

Introduction

The Internet of Things (IoT) consists of physical and virtual objects or resources, equipped with sensing, computing and communication capabilities. The IoT offers a great market opportunity for equipment manufacturers, Internet service providers and application developers [1]. With billions of sensors and other things already deployed, dealing with volume of data produced by the things, their varying capabilities, and an exploding number of services which they offer is regarded as a conceptual and technological challenge at present. To deal with it, common description and data representation frameworks to characterize things, their capabilities and data they produce, in machine-readable and interpretable form, are needed [2]. It is reasonable to believe that semantic technologies, based on application of ontologies [3], can facilitate interoperability.

The application scenario of fault detection has become increasingly wider in industrial sectors recently. In particular, vibration fault analysis attracts research interests as it is essential in daily operation and maintenance of electrical machines, tracks, bridges and so on [4]. A reasonable architecture of vibration fault analysis with high detection accuracy and deep analysis of collected data would be significantly desirable [5]. With the development of IoT technologies, we can take advantage of the merits in vibration fault analysis, and the achievement of highly efficient system is possible.

In this paper, we present a system architecture of semantic service for the Vibration Fault Analysis IoT (VFA-IoT) system. The remainder of the paper is organized as follows. Section II investigates the related work. Section III provides the architectural model of the system. Section IV introduces the design and implementation of VFA-IoT prototype. Section V shows the testing methods and result analysis. Section IV concludes the paper and envisions the future work.

Related Work

IoT deployments are finding extensive applications in scenarios such as transportation logistics, energy control and manufacturing [1]. Such applications use limited types of sensors, and the data usage they supply is well defined and targeted. The next stage will involve integration of a wider
variety of IoT data with more advanced data analytics. Achieving efficiency requires knowledge of the process and access to near-real-time data facilitated through IoT. [6], [7]

There are reports on research work and applications utilizing the vibration data to detect faults of devices or facilities [4], [5], [8]. While they provide functional supports in various aspects, most of them perform a simple treatment with the vibration data which results in low detection accuracy. Meanwhile, the fault detection results are often decided by artificial judgment. However, it is found that industrial IoT can detect or control a physical entity in a manner that is secure, reliable, efficient and real-time [9].

There is research work on adoption of semantic methods in the IoT at the level of ontologies. Most of them were developed within individual research projects and are hence prototypes. Meanwhile, the W3C SSN ontology, developed as a joint effort of several organizations, became the standard ontology for the semantic sensor networks [7]. IoT ontologies can be categorized as more generic ones and domain-specific ones focusing on aspects of sensors and sensor networks [2].

With current standards and proposed prototypes from industry and academia, applying IoT together with semantic service technologies to industrial vibration fault analysis is shown to be possible and promising. However, there is still a lack of a comprehensive systematic design for vibration fault analysis IoT with semantic service support covering real and complicated scenarios. The proposed approach and system in that style will be presented below.

**Architecture of VFA-IoT with Semantic Service Paradigm**

An overview of the architecture design of Vibration Fault Analysis IoT (VFA-IoT) is presented in Fig. 1. According to typical industrial IoT configuration, it is divided into the enterprise level, the gateway level and the endpoint level.

- **The Enterprise Level**: It deals with monitoring the overview status of the working field, performing high-level analysis of gathered data, making assessments and general decisions and sending control commands as feedbacks to lower levels.
- **The Gateway Level**: It is responsible for aggregating the data that are transmitted from the Endpoint Level and uploading some processing results to the Enterprise Level. It also issues or transfers control commands down to the Endpoint Level.
- **The Endpoint Level**: It includes a variety types of sensors and actuators associated with devices or modules to monitor field data. In scenarios of vibration fault detection, accelerometers are a typical kind of sensors extensively used to collect initial vibration data of interest.

![Figure 1. Architectural model of VFA-IoT.](image-url)
As for the SOA aspect, on each of the three levels, there resides services relevant to the tasks and constraints for that level. While there are data analysis and signal processing services on all the three levels, each level is supported by data services suitable to the design goal and capability of that level. For instance, the data processing service at the endpoint level is a composition of the vibration data pre-processing service, the vibration characteristics extraction service and other services involved.

The semantic service paradigm is applied into our VFA-IoT architecture with the following merits:

1. Abstraction: Because of the abstraction between service interface and service implementation, services can be mapped across heterogeneous software and hardware platforms.
2. Integration: Services can be flexibly integrated with other services, either statically or dynamically. Furthermore, services can be repeatedly composed into higher-level services to form service composites.
3. Robustness: It is recognized that building fault-tolerant systems from a collection of self-reliant components is more robust than if using a set of tightly interrelated components.

System Design and Implementation

Based on the architectural model presented previously, a prototype of VFA-IoT has been developed, including the monitoring control layer, the network layer and the device layer. The device layer contains two kinds of devices: CANopen master (CM) and CANopen slave (CS). They both use STM32F4 as micro-programmed control unit (MCU) to achieve complicated computation and system management. ADXL355 accelerometer is used for vibration detection. A more detailed description of the system can be found in [8].

The overview of data processing across field devices, gateways and high-level servers is as follows. First of all, the device performs the filtering and necessary preprocessing after collecting original vibration data from ADXL355 accelerometer. Then, signal processing such as RMS, FFT, PSD are performed. After that, processed data and characteristics are utilized by fault detection algorithms. Finally, the system provides the fault analysis information. Final results as well as processed data and some portion of original sensor data are output to storage in servers for later usage. The related semantic service integrated with the system is shown in Fig. 2.

![Figure 2. Semantic services integration with the VFA-IoT system.](image)

According to the system architecture and the data processing methods, an ontology is developed to define concepts and relationships among entities within the industrial vibration fault analysis environment. It provides an outline to build up semantic database that consumes RDF to represent the domain knowledge. The main purpose of that ontology is to classify things in terms of semantics and...
especially for describing policies used in data processing schemes. Fig. 3 shows a part of VFA-IoT Ontology document in OWL and a part of RDF data in N3 format for industrial fault analysis.

System Test

To evaluate the effective of the VFA-IoT approach, sufficient amount of testing has been done. Each part of the system is tested for its functionality and performance. A vibration test platform is set up in the lab. Then various vibration detection devices are installed on that platform for different experimental purposes. The structure and layout of the vibration test platform are shown in Fig. 4.

Based on the VFA-IoT infrastructure integrated with semantic services, motor vibration testing is performed to detect faults of various types. The fault signals are collected and analyzed with supporting of data processing services. A series of defects are picked up including that of inner race, outer race and rolling parts of a bearing. In the experiment, altogether 800 groups of vibration data are collected and processed. The characteristics of different categories of vibration signals in the motor testing is illustrated in Fig. 5. The results show that the method performs effectively in fault diagnosis of motor rolling bearings with inner-race faults, outer-race faults and rolling parts faults. the performance of VFA-IoT and the accuracy of fault diagnosis are satisfactory.
Conclusion

In this paper, an industrial vibration fault analysis IoT system with semantic service support is presented. The architectural model of VFA-IoT contains enterprise level, gateway level and endpoint level, with suitable vibration detection services located at each level. It is at each node in device layer that relevant services achieve signal processing such as FFT and low-pass filter to improve the detection accuracy in real-time. The study also proposes semantic services for fault analysis and ontology concerning devices and vibration data. Testing results indicate that the VFA-IoT approach and system design is reasonable in supporting real-time industrial vibration fault analysis.

Future work will be on improving the scalability of the system and integrating learning methods into the semantic services and composition processes to take advantage of the intelligence to further increase the system performance.

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