Semantic information model and mobile smart device enabled data acquisition system for manufacturing workshop

Yu Hu, Lianyu Zheng, Yahui Wang and Wei Fan
School of Mechanical Engineering and Automation, Beihang University, Beijing 100191, China
1 E-mail: lyzheng@buaa.edu.cn

Abstract. In the manufacturing workshop, various manufacturing resources and backward data acquisition methods seriously impede the intelligent acquisition and analysis of workshop data. At present, it is urgent to construct the semantic information model of workshop manufacturing resources by cross-platform standards, and establish the smart workshop by informatization, standardization and networking. What is more, digital and intelligent methods of data acquisition and process can improve production efficiency and reduce costs. In this paper, a semantic information model of workshop manufacturing resources is construct based on the standard protocol. Mobile smart devices are used to acquire data and build the workshop data acquisition system to overcome the problems in the manufacturing workshop. The framework of the data acquisition system is introduced at first. Then the QIF, OPC UA and MTConnect are modelled respectively, and the data acquisition system based on B/S architecture is built to realize the interaction between mobile smart device and server. The reliability and stability of the data acquisition system are verified by the manufacturing process of typical parts.

1. Introduction
Workshop data is the basis of workshop digitization and the core element of intelligent manufacturing and intelligent control [1]. Workshop data reflects the production activities of enterprise directly, and it is the fundamental basis for enterprise to make production management decisions and determine production plans and schedules. The real time acquisition of manufacturing workshop data is beneficial to the dynamic scheduling and optimal scheduling of production planning [2].

Taking the manufacturing process of a typical part as an example, the data generated can be divided into three categories: static data, dynamic data, and intermediate data. Static data does not change over time, such as part ID and worker number. Static data plays an important role in the binding and tracing of information. Dynamic data is the data generated during the manufacturing process with changes of the part state, such as part size and data generated by related equipment in the manufacturing process. These real time data reflect the quality and status of the part directly. The intermediate data is generated by calculating the static data and dynamic data due to the demand of enterprise management.

The manufacturing process of parts mainly produces dynamic data, which is not only various types, but also a large amount. The main reason is the variety of equipment in the manufacturing workshop, including: machine tools, sensors, gages and industrial robots. However, there are some challenges to acquire dynamic data in the manufacturing process. Firstly, each type of equipment has its own proprietary interface and communication protocol. Secondly, each type of equipment has its own
proprietary information model. Thirdly, the data acquisition workload is heavy for multi-type and cross-platform equipment. Therefore, it is urgent to standardize, unify and network the cross-platform communication protocol for equipment in manufacturing workshop, so as to improve the efficiency and reduce costs for the acquisition of manufacturing data.

The QIF (Quality Information Framework) standard is proposed by the DMSC (Dimensional Metrology Standards Consortium) of the ANSI (American National Standards Institute) for quality measurement [3]. According to the QIF standard in the field of quality measurement, the quality data of the part acquired by the gage in the workshop can be uniformly modelled and managed, laying the foundation for the analysis of the part quality data.

As a new generation communication framework, OPC UA has gradually become a communication solution in the field of manufacturing Internet of Things. At the same time, the concept of an information model is proposed, which provides various and more effective data semantics than traditional OPC. OPC UA focuses on industrial monitoring and has excellent interoperability. It is widely used in hardware communications and data acquisition in manufacturing workshop, such as sensors and industrial robots [4]. More and more researches have been paid attention on OPC UA. Lars Durkop et al [5] have proposed an ethernet automatic configuration system based on OPC UA. Max Hoffmann et al [6] have introduced OPC UA into the data acquisition of raspberry and PLC. Miriam Schleipen et al [7] have used OPC UA to monitor the Control system. At the present, the development of OPC UA mostly uses C++ and C#, but the demand for Web form is bigger. It should be focused on the development of JAVA.

MTConnect is a communication connection protocol which is developed by the AMT (Association for Manufacturing Technology). It has been widely applied and developed in machine tool data acquisition and monitoring [8]. So many researches have been focused on the MTConnect. Ray Y. Zhong and XuXun [9] have proposed a data acquisition scheme based on MTConnect for cloud manufacturing Internet of things. Xiaoqing Frank Liu et al [10] have used MTConnect to realize the data acquisition of machine tools, 3D printers and mechanical arms on cloud platform. P Lei and L Zheng [11] have proposed a MTConnect based monitoring system for finish machining the assembly interface of a vertical tail on a large passenger aircraft. However, at this stage, the development of MTConnect is focused on agents, and the adapters are less.

Although manufacturing data in the workshop is various, at this stage the military equipment manufacturing enterprises have a low level of digital control in the manufacturing process. It is far from enough to utilize and analyse manufacturing data [12]. There are two main problems. On the one hand, the method of data acquisition and recording in the manufacturing workshop is backward, and the level of automation and intelligence is low, and most still rely on manual recording and lack of data analysis and processing. On the other hand, the real time monitoring and data acquisition of the manufacturing equipment in the workshop cannot achieve.

As the mobile smart device has an open and extensible operating system platform, strong processing capabilities, and various human interaction methods, it has widely used in intelligent management and control of manufacturing workshop. On the one hand, the backward data acquisition mode of the workshop is improved and paperless operation is carried out. On the other hand, the workers can monitor the real time status of equipment and acquire data, which greatly improves the production efficiency and reduces the economic loss. The use of mobile smart device in the manufacturing field is becoming more and more widespread. Lei L et al [13] have proposed an engineering training mobile service system based on mobile Internet of things. Yin C et al [14] have used mobile in real time control the production quality information in workshop. Lei W et al [15] have introduced mobile into the workshop status real-time monitoring and management for MES. However, most mobile terminals use the C/S architecture, which is inefficient for data acquisition.

According to the study of literatures and some shortcomings of the current research, in order to solve the problems faced by the manufacturing workshop at the present stage. This paper proposes a semantic information model and mobile smart device enabled data acquisition system for manufacturing workshop, so as to improve the standardization of manufacturing data and the
intelligent of acquisition methods. Firstly, unified semantic modelling of different types of equipment in the manufacturing workshop. Secondly, propose the use of mobile smart device in manufacturing workshop, improving the backward data acquisition method. Thirdly, the data acquisition system is built based on the B/S architecture, and the interaction between the mobile smart device and the server is realized, as well as the real time monitoring and data acquisition of the workshop equipment.

The rest of this paper is following. The framework of the data acquisition system is proposed in section 2. Several key layers are detailed illustrated. Section 3 demonstrates the example verification of system. Discussion and conclusion is given in section 4.

2. Description of the data acquisition system
Figure 1 presents an overall architecture of the proposed data acquisition system, which is divided into several layers. They are equipment, mobile smart device and server. The data acquisition method of the mobile smart device for equipment is based on QIF, OPC UA and MTConnect. TCP/IP and WiFi are used for the communication between mobile smart device and server. SOA (Service-oriented Architecture) is used to design the whole system, and the LAN is built in the workshop [16]. The data acquisition system is deployed on the server, equipped mobile smart device for workers interacting with the server. Each layer and the interaction between layers are described in detail as follows.

2.1. Semantic information model
There are various types of equipment in the manufacturing workshop, each type of equipment has its own communication protocol and information model, so it is very complex to acquire data from many types and cross platform devices in the manufacturing workshop. Through the classification of equipment, three typical equipment is selected for standard semantic modeling. Then the QIF, OPC UA and MTConnect are modelled respectively. Semantic information model is the foundation of data acquisition system. By modeling the workshop equipment, the data of manufacturing workshop can be unified, semantic and standardized.

QIF is used for measurement data modeling. QIF uses XML to describe the information model of measurement data. XML schema definition language can automatically check syntax and consistency. The gages in the manufacturing workshop mainly include: calliper, micrometer and dialgage. figure 2 presents the model of the calliper measures a hole, in which the Id is 46, the feature Id is 42, the diameter is 10.003mm, the maximum value is 10.004mm, and the minimum value is 10.001mm.
Figure 2. QIF model of calliper.

Figure 3. OPC UA model of industrial robot.

Figure 4. MTConnect model of three-axis milling machine.
The proposed information model of the Huazhong three-axis milling machine based on MTConnect is illustrated in figure 4. MTConnect standard uses XML to describe the information model of a device (i.e. machine tool). The structural elements and data elements of XML represent the physical and logical parts of a device. Likewise, data elements are defined as XML elements that describe data that can be acquired from a device. The milling machine is named as BUAA-machine, mainly consisting of three components: controller, axes and systems.

2.2. Implementation of the data acquisition based on semantic information model

Figure 5. Implementation of the data acquisition.

Figure 5 shows the data acquisition process based on the semantic information model, which is the detailed description of the data acquisition for the mobile smart device layer to the equipment layer in the figure 1. As shown in figure 5, there are equipment layer, semantic transformation layer, and the mobile smart device layer.

In the process of data acquisition, the most important is the semantic transformation of the acquired data. Firstly, USB and TCP/IP are used for the data acquisition. Secondly, the data is transferred based on the semantic information model. Finally, data is visualized in mobile smart device. In section 2.1, three typical equipment are modelled by the QIF, OPC UA and MTConnect. According to the QIF semantic information model, the measurement data is transferred and finally converted to XML format. The acquired data by industrial robot is transferred based on OPC UA semantic information model. MTConnect semantic information model is also described by using XML. The machine tools data is transferred based on MTConnect semantic information model.

2.3. Communication

During the acquisition of manufacturing workshop data, the data is transmitted from the equipment to the mobile smart device and the server in turn. It involves the communication between the equipment and the mobile smart device, as well as the communication between the mobile smart device and the server. Due to the types of equipment in the manufacturing workshop are various. The communication between the equipment and the mobile smart device is not unique. USB and RS232 are used for connecting gages. RS232 may be used for sensors. Large scale equipment such as machine tools and
industrial robots mainly use the TCP/IP. What is more, TCP/IP and WiFi are used for the communication between mobile smart device and server.

In the data acquisition system, USB is used to gages, so that the complex configuration of RS232 is avoided. Industrial robots and machine tools use TCP/IP to ensure the stability and security of data acquisition. The mobile smart device and the server use WiFi to communicate, so that the use of mobile smart device will not be limited.

2.4. Interaction
The data acquisition system is deployed on the basis of B/S architecture and released at the server of the manufacturing workshop. The mobile smart device connects to the manufacturing workshop LAN and logs in to the data acquisition system of the server through the browser. The various functions of mobile smart device facilitate the acquisition of manufacturing data, including scan, NFC and camera. The interaction between the server and the mobile smart device ensures the accurate assignment of acquisition tasks and the real time acquisition of manufacturing data. Authority management of the mobile smart device and the interaction of the acquisition task is described as follows.

2.4.1. Authority management of mobile smart device. The data acquisition system is based on the B/S architecture, which simplifies the development, maintenance and use of the system. The mobile smart device accesses the system only by installing a browser. The maintenance and upgrade of the system is convenient. It only needs to be changed on the server, and the mobile smart device can synchronize.

The data acquisition system has the function of worker authority management. The administrator has the highest permission, and all workers can be unified managed and authorized by the server. The administrator assigns different authorities to each worker according to their duties, so that each worker has different permissions on the system. Workers access the acquisition system by logging in to their own accounts through mobile smart device, and the commands and acquisition tasks assigned from the server are different. Through the function of authority management, workers are responsible for their duties and tasks, which greatly improve the efficiency of the data acquisition system and the acquisition of data in the workshop.

2.4.2 Interaction of acquisition task. According to the process flow, the manager makes the acquisition task, delivering the task to the designated worker through the server. The worker uses the mobile smart device to execute the task after receiving the task in real time. After the data acquisition task is completed, the acquisition results are uploaded to the server for saving and analysis. The status of tasks is divided into three types: unexecuted, executed and completed. The tasks that have been executed can be viewed and analyzed.

3. Case study
This section takes the manufacturing process of a typical part in the workshop as an example. The data acquisition system is used for data acquisition and real time monitoring of the manufacturing process.

3.1. The laboratory testbed
The laboratory testbed includes a workpiece, a Huazhong milling machine, a KUKA industrial robot and a digital calliper. The milling machine is used to process the part, and the industrial robot is used to carry part, and the digital calliper is used to acquire the quality data of the part. At the same time, three mobile smart devices are equipped with three work stations, and a laptop is used as a server and builds a workshop area network. Mobile smart devices and laptop interact task through WiFi.

3.2. Data acquisition process and results
After the completion of laboratory testbed, the data acquisition system can be deployed and the data acquisition can be started. The following is the process and results of data acquisition in the whole manufacturing process.
Firstly, the administrator logs in to the server and assigns the data acquisition tasks for the milling machine operator, the industrial robot operator, and the digital calliper operator. The operator uses the mobile smart device to log in and receive tasks through their own username and password.

Secondly, before each process operation, the operator needs to scan the QR code on the part by the mobile smart device to read and confirm the part information, as shown in figure 6(a).

Thirdly, part processing is carried out on the milling machine. The milling machine operator connects the machine with a mobile smart device and monitors the machining process in real time based on MTConnect, as shown in figure 6(b). After completing the data acquisition, it can be viewed and analysed, and finally uploaded to the server.

Then, after the processing, the industrial robot is used to clamp the part. The industrial robot operator can monitor the robot in real time based on OPC UA, as shown in figure 6(c).

Finally, after the industrial robot clamping the part to the examination workstation, the quality checker connects the mobile smart device and the digital calliper to measure the machining dimensions of the part, as shown in figure 6(d).

4. Conclusions
This paper introduces the semantic information model and mobile smart device enabled data acquisition system for manufacturing workshops. Three kinds of modelling methods for different equipment types in manufacturing workshops are proposed, which are QIF, OPC UA and MTConnect. Then the mobile smart device is introduced, in order to improve the digitalization and intellectualization of the data acquisition and processing mode of the workshop. Based on the standard protocol and mobile smart device, the B/S architecture of the data acquisition system is proposed, and the interaction between mobile smart device and server is realized. Finally, the stability and reliability of the data acquisition system are verified through the manufacturing process of the typical part.

Some highlights of this study can be summarized as follows.

- To classify different types of equipment in manufacturing workshops and use different semantic information models to model. Workshop information can be unified, semantic and standardized, and the data acquisition efficiency is improved.
- According to the backward data acquisition and processing method, the use of mobile smart device is proposed, which improves the data acquisition efficiency of the workshop and the work efficiency of the workers.
- The data acquisition system is based on B/S architecture, which simplifies the development and maintenance of the system. At the same time, the interactive mode of mobile smart device and server is proposed, and the authority management and data acquisition tasks management improve the efficiency of the acquisition system.
- The research also has some shortcomings, which can put more effort into the future research.
- The data acquisition system is only applicable to manufacturing workshops and not widely applicable.
- The equipment is modelled based on the standard protocol, and only the reading of manufacturing data is realized. What is more, the OPC UA can also control the equipment.
Acknowledgments
This research is funded by the postgraduate innovation practice base of the modern design and advanced manufacturing technology for complex products in Beihang University, and the Civil Airplane Technology Development Program (MJZ-2016-G-62).

References
[1] Liu J J, Zhu W H, Soulier E and Remy S 2014 Research on Techniques of Intelligent Manufacturing Data Management Adv. Mater. Res. 1039 449-455
[2] Windmann S, et al. 2015 Big Data Analysis of Manufacturing Processes J.Phys. 659 012055
[3] Dimensional Metrology Standards Consortium(DMSC) 2015 Quality Information Framework (QIF) Part 2-Library 1-2
[4] Schleipen M, Gilani S S and Bischoff T 2016 CIRP Int. Conf. on Manufacturing Systems(Stuttgart) 57 (Amsterdam: Elsevier) 315-320
[5] Dürkop Land Imtiaz J 2013 IEEE Int. Conf. on Industrial Informatics(Bochum) 248-253
[6] Hoffmann M and Thomas P 2017 IEEE Int. Conf. on Industrial Informatics(Paris) 744-747
[7] Schleipen M 2008 IEEE Int. Con. on Emerging Technologies and Factory Automation(Hamburg) 640-647
[8] Lee B E, Michaloski J and Proctor F 2010 ASME Int. Design Engineering Technical Conferences(Montreal) 1183-1190
[9] Zhong R Y, Wang L and Xu X 2017 CIRP Int. Conf. on Industrial Informatics(Taichung) v 63(Amsterdam: Elsevier) 709-714
[10] Liu X F, Shahriar M R and Sunny S M N A 2016 ASME Int. Design Engineering Technical Conferences and Computers and Information in Engineering Conf.(Charlotte)
[11] Lei P and Zheng L 2017 MTConnect compliant monitoring for finishing assembly interfaces of large-scale components: A vertical tail section application J. Manuf. Syst. 45 121-134
[12] Wu H, Liu Z and Wu Y 2017 Design of Data Acquisition and Intelligent Monitoring System for Military Manufacturing Enterprises Ordn.Indu.Auto 36 22-27
[13] Lei L and Dai Q 2017 IEEE Int. Conf. Consumer Electronics-China(Guangzhou) 1-4
[14] Yin C, Wang M Y, Li X B and Yin H K 2015 Real-time control support system of workshop production quality information based on mobile terminals CIM 21 169-179
[15] Lei W 2014 The Design and Development of the Mobile Terminal Based on MES Adv. Mater. Res. 962-965 2928-2931
[16] Morgan J and O’DonnellGE 2015 CIRP Int. Conf. on Intelligent Computation in Manufacturing Engineering(Capri) 33(Amsterdam: Elsevier) 29-34