An IoT Based Solution for Cyber-Physical Fusion in Shop-Floor

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Abstract. Smart manufacturing plays an important role in the transformation and upgrading of manufacturing industry and the China Manufacturing 2025 Strategy. And the cyber-physical fusion is a critical process to achieve the interconnection and interoperability between the cyber and physical world of manufacturing. Combing with IoT, a solution to realize cyber-physical fusion for heterogeneous objects in shop-floor is presented. The architecture and key technologies of the solution are investigated. Then a remote management platform is implemented. Logistics tracking, production visualization, equipment interconnection and remote operation are realized and can be remotely accessed by portable terminals via Internet. The proposed solution is verified by the actual machining and assembly workshop in a laboratory at Harbin Institute of Technology.

Keywords: Cyber model · Cyber-physical fusion · Cyber physical systems Equipment interconnection · Internet of things · Radio frequency identification

1 Introduction

With strong integrity and comprehensiveness, intelligent manufacturing is now one of the focusing points of advanced manufacturing mode [1], as well as the critical measure for the transformation and upgrading of Chinese manufacturing industry, one of the key contents of China's "13th Five-Year plan" [2]. Therefore, the research on combining advanced manufacturing with information technologies has grown significantly.

Cyber Physical Systems (CPS) is a new paradigm of manufacturing proposed to achieve the interaction between the physical and the computing processes by closed loop feedback [3, 4]. And the realization of CPS depends on the interconnection and interoperability between physical and cyber world. However, the cyber-physical fusion for shop-floor is still under development [5]. On the other hand, promoted by the growing application and reducing cost of sensors and wireless network technology, Internet of things (IoT) technologies such as RFID [6] and ZigBee [7] are increasingly applied in shop-floor to meet the needs of real time information collection, item tracking and production monitoring [8].

Aiming at the interaction of heterogeneous objects in cyber physical shop-floor system, this paper attempts to provide an IoT based solution for cyber-physical fusion in shop-floor. The architecture of the IoT system was proposed based on the definition

G. Q. Huang et al. (eds.), *Proceeding of the 24th International Conference on Industrial Engineering and Engineering Management 2018*,
https://doi.org/10.1007/978-981-13-3402-3_24

of cyber models of machining and assembly shop-floor. The key technologies and the methods of applying them are investigated. At last the system was implemented in an actual shop-floor.

2 Design of the IoT System

2.1 Cyber Models for Shop-Floor

The accuracy of cyber model reflecting physical world is decided by the comprehensiveness and typicality of physical characteristics chosen while building cyber model [9]. The feature analysis and classification for all manufacturing equipment in shop-floor is needed before the design of the IoT system because of the diversity and heterogeneity of equipment in workshop. And we also need to define a variety of Data Acquisition (DAQ) solutions for different kinds of objects so as to realize the fusion of physical and cyber efficiently and precisely. There are mainly two stages of processing in a typical shop-floor, namely, machining and assembly. Cyber models for machining and assembly are constructed through the definition of their input and output which is able to provide supports for the design of the IoT and DAQ systems.

2.1.1 Cyber Model for Machining

Machining is defined as the series of actions in the specific external working environment that are taken to change blanks into components or production according to ordered process scheme utilizing the status and ability of manufacturing equipment [10]. The input of the processing is a quadruple, (Machine info, Environment, Order info, Part status), while the output of machining could be defined as a triple, (Machine status, Quality, Efficiency). The detailed description of machining cyber model is illustrated in Fig. 1.

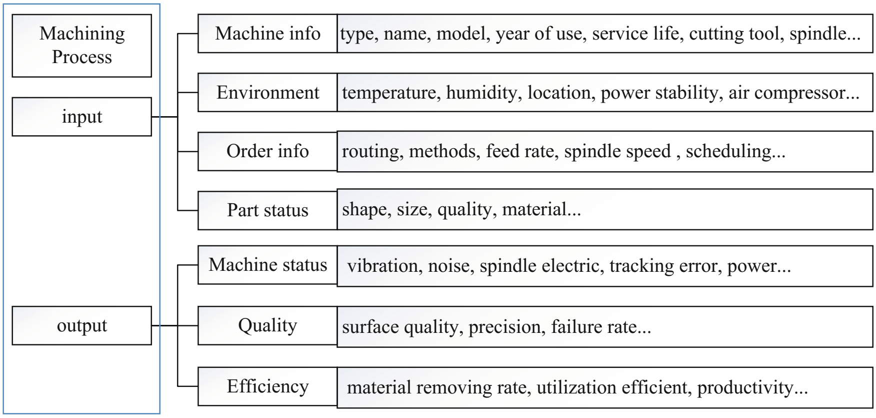

Fig. 1. Cyber model for machining

Through data acquisition and analysis of physical equipment based on machining cyber model, the relationship between status of machine tools and product quality can be discovered. This could provide guides for the design, process and maintenance of machines. And also it could provide evidences for machining technology of components, making product scheduling and analysis of power cost.

2.1.2 Cyber Model for Assembly

There are two kinds of key entities in an assembly shop-floor: warehouse and workstation. The warehouse is the starting and ending point of assembling work. And the workstation is where the components or parts assembled. They form the closed loop of assembly process. As shown in Fig. 2, the input info of warehouse could be represented as a tuple (Order, Stagey), which includes mission orders and inventory strategy. The output info is warehouse status including inventory load, cost, reliability and the like. We get these data through acquiring inventory volume timely. The input info of workstation is a triple, (Component status, Process scheme, Worker Status). And the output could be presented as (Assembly quality, Assembly efficiency). Through real time acquisition of relating characters in warehouse and workstation, the cyber model of the entire assembly line could be built, so the whole assembly process monitoring and analysis could be achieved.

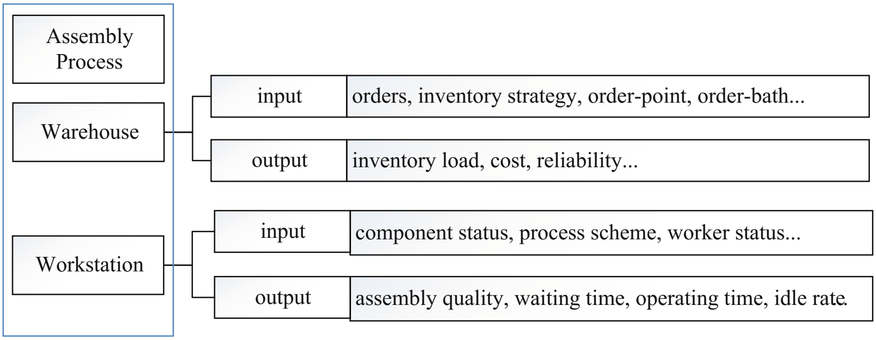

Fig. 2. Cyber model for assembly

2.2 IoT Based Architecture for Cyber-Physical Fusion

Combining the features and demand of machining and assembly shop-floor, the IoT based architecture for cyber-physical fusion is constructed as shown in Fig. 3.

The architecture consists of three layers. The bottom is the physical layer. The logistics information of assembly shops is acquired through the RFID system, while the equipment status data is acquired by the sensors and virtual instruments. The middle layer is the cyber layer, the database structure and data tables are designed and deployed in this layer, and the data are stored in the database server in real time through the LAN. The top layer is the application layer. In this layer, the database is used as medium, and the foreground applications are developed to realize remote monitoring. The three-layer system architecture enables the interconnection and communication

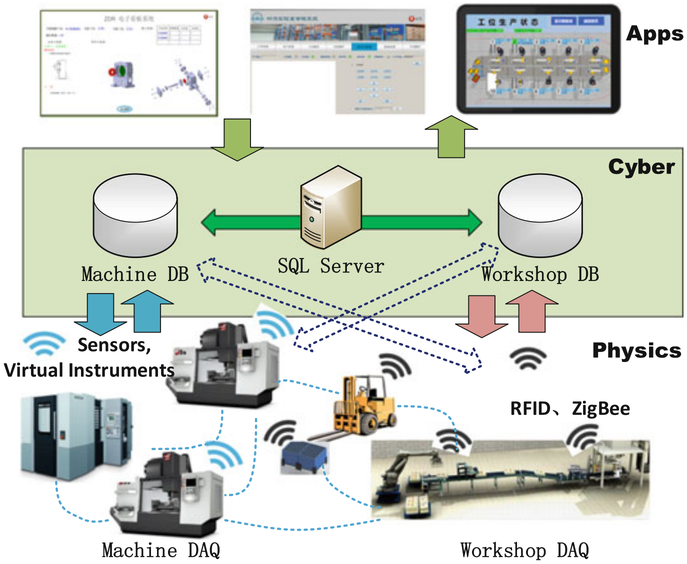

Fig. 3. IoT based architecture for cyber-physical fusion

between heterogeneous production facilities and resources, forming an IoT system that things cooperate with each other which can support efficient and personalized production.

3 Key Technologies of IoT Based Cyber-Physical Fusion

3.1 RFID Based Logistics Tracking

Radio Frequency Identification RFID is a noncontact automatic identification technology, which signals through radio frequency automatic identification and access to relevant target data, no need for manual intervention to identify job [11]. RFID systems consist of Radio Frequency (RF) tags, or transponders, and RF tag readers, or transceivers [12]. When RF tag readers are installed on each workstation, they can automatically identify and query information of products on the assembly line correspondingly. Therefore, it is convenient for workstation operation and production management.

RFID tags should be plastered on containers and the body of reducers, in order to identify and track products or components. The process of the data acquisition and transmission can be described as follows: Step 1, after the order arrives, the system sends task instructions to sorting rack. Workers get all the necessary components from the sorting rack and then put them into one container. The counter in the sorting shelf will send the number of components taken away to the server automatically through the ZigBee node. Step 2, AGV can identify the RFID tags of containers and distribute components to the corresponding stations. Step 3, when the product comes into a workstation, the RFID reader will identify the product, send the product ID to the server and display the operation animation of the process to assist operators. Step 4, the workstation sends out the instructions of the product processing, and the AGV carries the end product with the unique RFID into the warehouse after the quality inspection.

3.2 ZigBee Based Interaction of Logistics Equipment

ZigBee, based on a Wireless Sensor Network (WSN) standard, is a wireless short range transmission technology. It features a cost effective, low power and multihop wireless communication in a selforganized mesh network [13].

Logistics equipment in a typical shop-floor includes storage racks, conveyor belts, manipulators and handling equipment. In order to build the ZigBee network of logistics equipment, ZigBee nodes should be installed into PLCs of the equipment while the ZigBee server should be connected to the server computer. We use different methods to acquire data from different equipment, as described next.

(1) Manipulator. The ZigBee node is installed in the PLC of the manipulator with DAQ channels connected to the registers of PLC. The monitoring and control of the manipulator are realized by reading and writing the registers.
(2) Conveyor belt. Same as the manipulator, the ZigBee node is installed in PLC. What's more, in order to monitoring the materials conveyed by the conveyor, a photosensitive sensor is installed and connected to the ZigBee node.
(3) Storage rack. Counters are installed in the rack to collect the inventory data. And ZigBee nodes are connected to the counters in order to send the data to the server computer.

With these solutions, the ZigBee network can meet the needs of real time inventory monitoring, manipulator control, conveyor belt load monitoring and so on.

3.3 Virtual Instrument Based Machine Tool Monitoring

Virtual instrument (VM) technology is the use of high performance modular hardware, combined with efficient and flexible software to complete the application of various testing, measurement and automation applications. The basic thought of using VM is to realize measurement and control functions through software and panels in computer [14]. And LabVIEW is an integrated development environment developed by NI for industrial testing applications. It offers a graphical programming approach that empowers users to visualize every aspect of applications, including hardware configuration, data measurement, and debugging [15].

The acquisition, communication and storage of the state information of machining equipment are carried out by the LabVIEW program based on the C/S architecture. The C/S architecture realizes the separation between data acquisition terminals and data processing terminal, so that the acquisition terminals can use adequate CPU resources for acquisition, so as to reduce the cost of the acquisition terminals and achieve multisource data acquisition. The signals that we need to acquire from the processing equipment are vibration, noise and power. The DAQ system can realize the real time acquisition, processing, analysis and storage of the state data of the equipment.

Figure 4 shows the framework of the system. The machine tool vibration and noise signals are collected by sensors, then processed by PXI, finally transmitted to the computer through network. The power signals are acquired by the power meter, then transmitted to the computer through RS232. Finally the computer would process and synchronize the data from local PC to database.

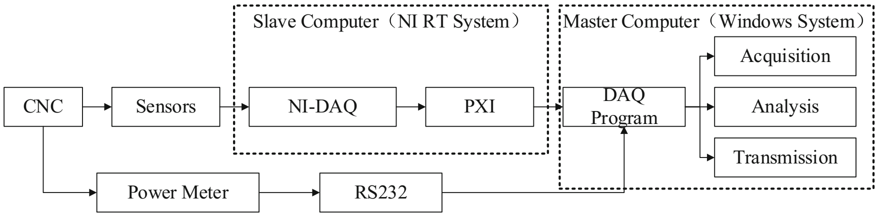

Fig. 4. Architecture of data acquisition system for machine tools

The overall design of the software framework consists of four parts: data acquisition, data receiving, data processing and database interaction, and the software is programmed using LabVIEW. The data acquisition part is the function of the server and the other three parts are the functional modules of the client. Figure 5 shows the operation workflow. The module of vibration DAQ and power DAQ collects the data. The vibration signals should be transmitted to the client through TCP by sending and receiving module. Then the computer extracts features and stores them to database. Meanwhile, the power signals are collected and stored directly by the computer. The software can be used to collect data for experiments, as well as real time online monitoring.

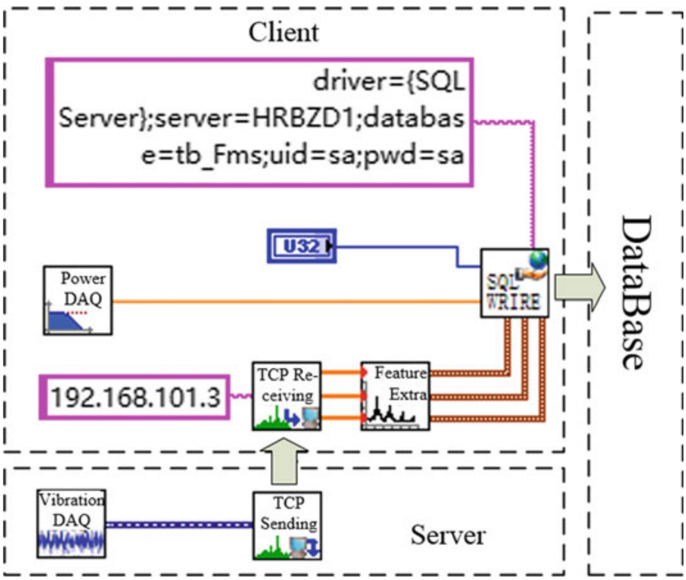

Fig. 5. Framework of the data acquisition software

4 System Implementation

4.1 Implementation of IoT

A prototype system based on the presented architecture of IoT based physical-fusion system for shop-floor was developed in order to verify the monitoring and management capability of the system for multitype and multilocation equipment involved in the typical production workshop. The structure of the IoT system implemented was presented in Fig. 6. It has two workshops connected to the IoT network over the Internet, one is an assembly workshop and the other one is a machining workshop. The assembly workshop includes an assembly line, manipulators, AGVs, storage racks and so on, while the machining workshop includes machine tools for subtractive manufacturing and 3D printers for additive manufacturing. The RFID readers, ZigBee nodes and sensors are installed in the corresponding equipment and connected to the Internet through LAN in the workshops. The collected data will be gathered to the database in the assembly workshop.

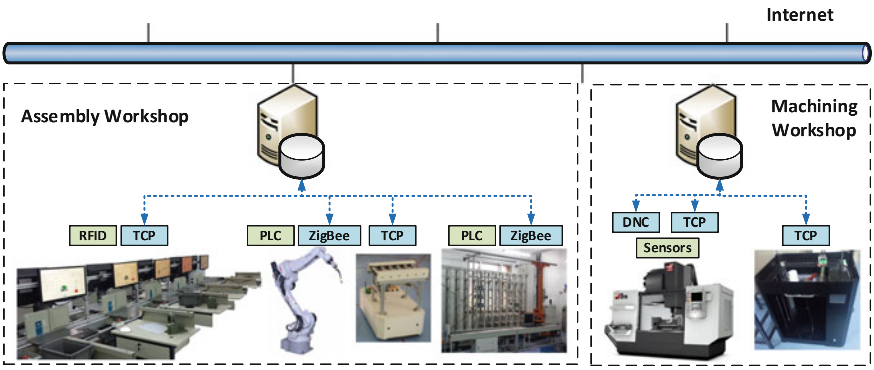

Fig. 6. Structure of the prototype system

4.2 Architecture and Mechanism of the Management Platform

Tasks in the assembly shop-floor are procuring or getting the components according to order lists, generating production plan, organizing production and delivering timely. The expected applications for assembly shop-floor are intelligent scheduling, assembly line balancing, motion analysis and so on. On the other hand, the machine tool needs to process the blanks into components according to MRP. The application of energy consumption analysis, equipment maintenance and productivity prediction need to be developed.

In order to meet the requirements of production and scientific research, a management platform was developed on the basis of the IoT system. It includes three modules: assembly line management, machine tool management and system management, which is illustrated in Fig. 7. In the module of the first one, users could get

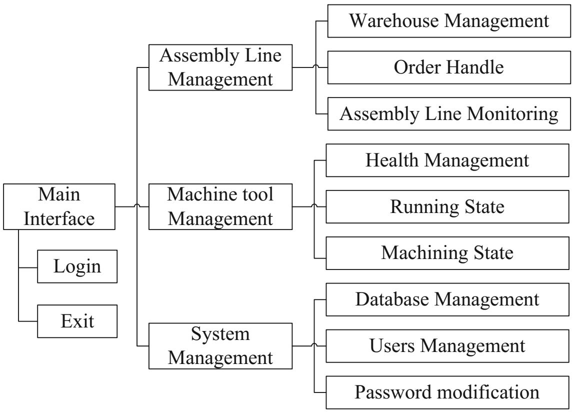

Fig. 7. Function structure diagram of the management platform

the state of assembly line through visualization interface, as well as monitor and control the logistics in real time. For the second, the health state and working state of machines are monitored and these are the fundamental for equipment maintenance and production plan. Each function module could fulfill the check and update of information in real time correspondingly.

4.3 Remote Monitoring and Control

The tablets with Windows10 operation system are chosen as the portable terminals to run the management platform. Once the equipment is networking, the platform is accessible. With accordingly accounts and passwords, users can access to the main interface. The menu shows the guidance for all sections and by clicking on the project, users can get into the selected module.

The interface of assembly line monitoring is shown in Fig. 8. The workstations displayed in the interface are workstation number 1–10 in the workshop. Each station has three parameters, workstation ID, state and number of finished products, showing the real time status of the assembly line. On the top left corner, it shows the number of Work-In-Progress (WIP) in the assembly line and the cycle time calculated according to the interval of two kinds of reducers which can be used to evaluate the efficiency. If an end product is completed in the No. 10 workstation, the system will assign a transport task to the AGV to deliver the product to warehouse.

In the equipment status monitoring module, there are three tabs which are health management, running state and machining state. Figure 9 shows the interface of the health management and it can be divided into four sections, inquiry section, basic information section, detailed data section and tool offset calculation section. In the inquiry area, users search for the data of machines based on equipment type, its location, ID and so on. When one machine tool in the equipment list is selected, sections of basic information and detailed data will show the information correspondingly. One of the main functions of running state interface is plotting the power curve of machines. When the button named Show Figure is clicked, the data of power

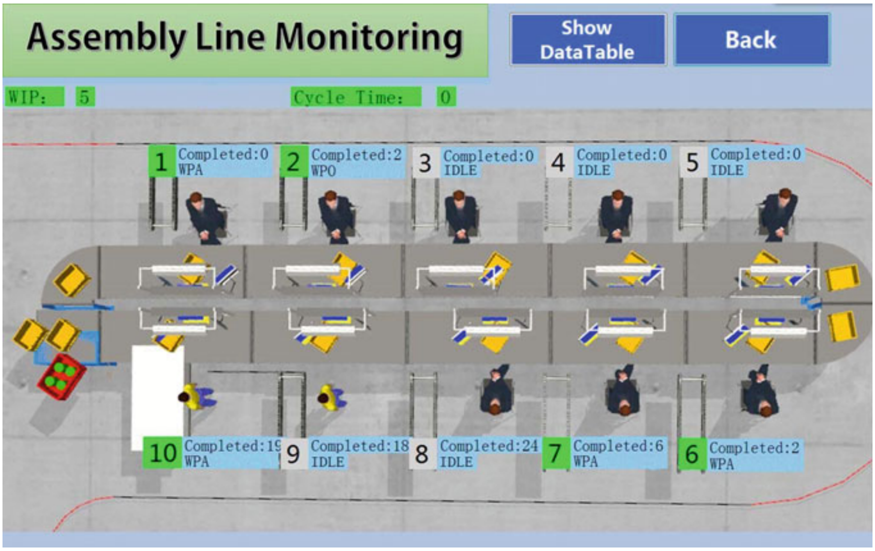

Fig. 8. Interface of assembly line monitoring

in the database will be extracted and the power curve will be plotted, so the power of machine could be monitored remotely in real time.

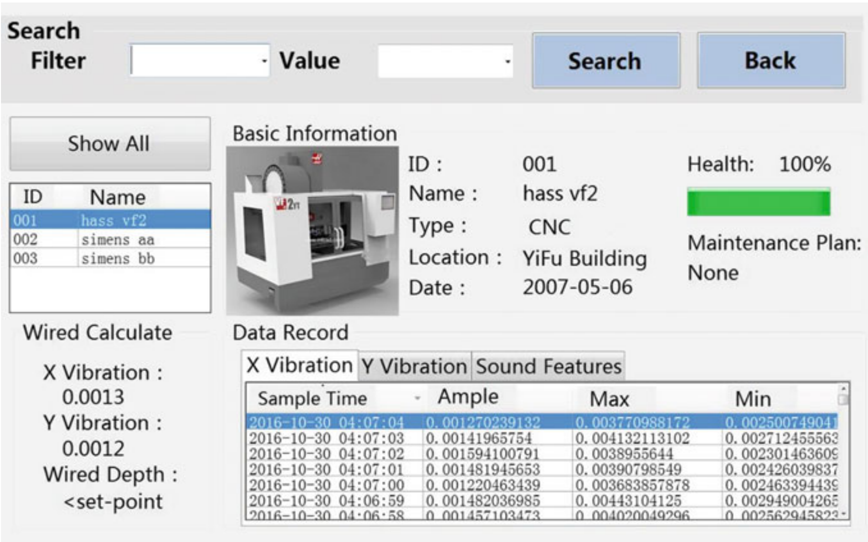

Fig. 9. Interface of equipment health status

5 5 Conclusion

This paper proposed an IoT based solution to develop the cyber-physical fusion system for shop-floor. From the perspective of typical shop-floor, the production process was divided into two stages, namely, machining and assembly. The features of cyber models and the methods to build the IoT system for each stage is demonstrated. Then an IoT based architecture for cyber-physical fusion was proposed. The key technologies related and their implement methods are discussed. At last, a prototype system based on the proposed architecture was developed and verified in the actual machining and assembly workshops. This paper practiced CPS and IoT in the shop-floor level, and achieved the interoperability and interaction between heterogeneous objects in a manufacturing system, providing technique supports to promote the production mode combining with information technology and advanced manufacturing industry.

Acknowledgements. This work is funded by NSFC-NSF (Grant No. 51561125002).

References

1. B. Chu, W.J. Tolone, J. Long, W.J. Tolone, R. Wilhelm, Y. Peng et al., Towards intelligent integrated manufacturing planning-execution. Int. J. Agil. Manuf. (in press)
2. J. Fu, Development status and trend of intelligent manufacturing equipment (in Chinese). J. Mech. Electr. Eng. **31**(08), 959–962 (2014)
3. E.A. Lee, Cyber physical systems: design challenges, in *11th IEEE Symposium on Object Oriented Real-Time Distributed Computing (ISORC)* (IEEE Computer Society, Orlando, FL, USA, 2008), pp. 363–369
4. J. Lee, B. Bagheri, H.A. Kao, A cyber-physical systems architecture for industry 4.0-based manufacturing systems. Manuf. Lett. **3**, 18–23 (2015)
5. F. Tao, W. Liu, J. Liu, X. Liu, Q. Liu, T. Qu et al., Digital twin and its potential application exploration (in Chinese). Comput. Integr. Manuf. Syst. **24**(1), 1–18 (2018)
6. R. Want, An introduction to RFID technology. IEEE Pervasive Comput. **5**(1), 25–33 (2006)
7. H. Yang, L. Yang, S.H. Yang, Hybrid Zigbee RFID sensor network for humanitarian logistics centre management. J. Netw. Comput. Appl. **34**(3), 938–948 (2011)
8. Y. Zhang, G. Zhang, J. Wang, Real-time information capturing and integration framework of the internet of manufacturing things. Int. J. Comput. Integr. Manuf. **28**(8), 811–822 (2015)
9. C. Hein, T. Ritter, M. Wagner, Model-driven tool integration with ModelBus, in *Workshop Future Trends of Model-Driven Development* (2009), pp. 50–52
10. S. Kalpakjian, S.R. Schmid, *Manufacturing Engineering and Technology* (Pearson, Upper Saddle River, NJ, USA, 2014), pp. 468–476
11. R.Y. Zhong, Q. Dai, T. Qu, RFID-enabled real-time manufacturing execution system for mass-customization production. Robot. Comput.-Integr. Manuf. **29**(2), 283–292 (2013)
12. X. Wu, Y. Wang, J. Bai, H. Wang, C. Chu, RFID application challenges and risk analysis, in *2010 IEEE 17th International Conference on Industrial Engineering and Engineering Management (IE&EM)* (IEEE, 2010), pp. 1086–1090
13. H. Christian, C. Weigand, J. Bernhard, Wireless medical sensor network with ZigBee, in *Proceedings of the 5th WSEAS International Conference on Electronics, Hardware, Wireless and Optical Communications*, Madrid, Spain, 15–17 February 2006, pp. 12–15

14. I. Orovic, M. Orlandic, S. Stankovic, Z. Uskokovic, A virtual instrument for time-frequency analysis of signals with highly nonstationary instantaneous frequency. IEEE Trans. Instrum. Meas. **60**(3), 791–803 (2011)
15. C. Elliott, V. Vijayakumar, W. Zink, R. Hansen, National Instruments LabVIEW: A programming environment for laboratory automation and measurement. J. Assoc. Lab. Autom. **12**(1), 17–24 (2007)