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基于云制造的物联网实时状态监控

An IoT-enabled Real-time Machine Status Monitoring Approach for Cloud Manufacturing

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Abstract

学术和实践

Cloud Manufacturing (CMfg) has attracted large number of attentions from both academia and practitioners. One of the key concepts in CMfg is service sharing which is based on the availability of various manufacturing resources. This paper introduces an Internet of Things (IoT) enabled real-time machine status monitoring platform for the provision of resource availability. IoT technologies such as RFID and wireless communications are used for capturing real-time machines' statuses. After that, such information is visualized through a graphical dashboard after being processed by various data models and cloud-based services over smart phones. A demonstrative case is given to illustrate the feasibility and practicality of the proposed system. In this case, IoT devices are deployed in a CMfg environment such as shop floors to capture machine data firstly. Secondly, cloud-based services are designed and developed for making full use of the captured data to facilitate end-users' production operations and behaviors. Thirdly, '5w' questions are answered by using both real-time and historic data generated from the frontline CMfg sites.

RFID和无线技术

捕捉实时状态

Peer-review under responsibility of the scientific committee of The 50th CIRP Conference on Manufacturing Systems

1. 获取数据
2. 优化产品和系统
3. 解决5w问题

Keywords: Cloud Manufacturing; Internet of Things; Real-time; Machine Monitoring.

1. Introduction

Cloud manufacturing (CMfg), supported by cutting-edge technologies and advanced concepts, refers to a new manufacturing paradigm which enables full sharing manufacturing resources that are encapsulated as services [1-3]. Cloud computing and Internet of Things (IoT) are core supporting technologies in CMfg where typical resources such as workers, machines, materials, logistics items, and production jobs are converted into smart manufacturing objects (SMOs) so that they are able to sense and react with each other in a cloud based intelligent environment [4, 5]. One typical and impressive example is that processed materials/components are tagged by radio frequency identification (RFID) technology so that they could be real-time tracked and traced [6]. With such real-time information, manufacturing logistics within or outside of a factory could be monitored. Moreover, such materials' or components' real-time information like availability, location, and quantity could be shared with other manufacturing departments or even other companies. That ultimately achieves a full sharing of CMfg in terms of information flows and materials' physical operations such as their movements and past delivery trajectories [7]. Cyber-physical systems (CPS) in cloud manufacturing was also attracted with large number of attentions. CPS was explained and compared with CMfg so as to fully understand CPS and its future potential in manufacturing [8]. A cloud-enabled prognosis for manufacturing was presented by highlighting the techniques as well as their influences [9]. Advanced manufacturing relies on the timely acquisition, distribution and utilization of information from logistics and machines.

完全共享制造资源

在云智能环境的基础上实现感知和互相交流

加工材料和物件通过RFID可以实时追踪

预知/预测

However, CMfg not only tries to share the material logistics information, but also the key production resources for example machines [10]. Manufacturing machines are crucial for a company because they are the most value-adding points. On-line smart process monitoring in the machining was realized through connecting the computing and services in the cloud to the machine tools [11]. Thus, they must be converted into crucial services which could be shared and circulated within CMfg [12, 13]. However, there are some challenges. Firstly, it

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is difficult to label manufacturing machines so that they could be identified. Currently, most companies use numbering system for this purpose. For example, machine labelling number or asset code are used for identifying various machinery. These numbers are mainly used for assets management. Secondly, barcode technology has been used for identifying machines [13]. In practice, with adoption of cloud computing, manufacturing requires management applications with ubiquity and effectiveness of processes are enabled [14]. Unfortunately, there are some drawbacks using barcode in manufacturing machines. For instance, they are easily polluted by dusts and oils in the practical manufacturing sites like a shop floor, thus they cannot be scanned. Thirdly, under the CMfg era, companies always want to know who did what, when, where, and why that are termed as '5w' questions. Traditional approaches like phone calls, e-mails, and on-site visits are commonly used for obtaining such information which will not be recorded precisely and instantly. Energy consumption of machine tools is able to significantly improve the environmental performance of manufacturing systems [15]. Monitoring the status of machines is important then due to the variety of different types of machining equipment. A MTConnect standard was used for a monitoring system for collecting the data based on a modern manufacturing shop floors [16]. However, real-time statuses of machines are hard to achieve based on these traditional approaches which sacrifice large number of labor and time.

In order to address the above challenges, this paper proposes an IoT-enabled real-time machine status monitoring approach for CMfg so that the '5w' questions could be easily answered. First of all, IoT devices, specifically RFID readers and tags are systematically deployed in typical manufacturing sites like shop floors so that various resources could be identified. After that, they are able to sense with each other automatically to get the real-time information. Secondly, the sensed and captured information will be organized by a set of data models which are able to identify, process, and format the key data into a standardized scheme for further usages such as production planning and scheduling. Thirdly, with the standardized data scheme, a cloud-based smart view service will make full use of these data for visualizing the real-time status of working machines. The real-time status monitoring service not only reflects the current conditions, but also shows the historic data through various graphical fashions such as bars, curves, etc.

The rest of this paper is organized as follows. Section 2 presents an overall architecture of the proposed approach which is a hierarchical system framework. Several key layers are detailed illustrated. Section 3 reports on a demonstrative case study which shows how the proposed approach could be used by typical manufacturing companies. Deployment of various IoT devices and designed & developed services is detailed given based on a laboratory testbed. Finally, conclusion section highlights our contributions and future research directions so as to improve this work.

Fig. 1. Architecture of IoT-enabled real-time monitoring

2. Overall architecture

Fig. 1 presents an overall architecture of the proposed IoT-enabled real-time machine status monitoring solution which is divided into several layers. They are smart machines, smart conn, data model and smart view. Service-oriented architecture (SOA) is used for designing and developing various services that could be deployed in a cloud so that end-users are able to access them easily [17, 18]. SOA is able to facilitate data resources and computational functions as services available on a network so as to support the distributed cloud manufacturing [19]. The following sub-sections present detailed information for each layer.

2.1. Smart machines

This layer includes several sub-layers which are consisted by different categorized components. First of all, various sensors such as RFID readers and tags, vibration sensors, temperature sensors, and force sensors are deployed into various components and machines. Secondly, critical components, cutting tools, machine controllers, and data acquisition devices are included in this layer. They may carry different sensors so that their statuses could be real-time tracked and traced. Finally, typical machines and robots may use different tools (e.g. cutting tools) for different processes. Thus, they are identified by RFID devices. For example, RFID tags are attached on each individual machine so that it can be uniquely identified [20-22].

After the deployment of various sensors on different manufacturing resources, a smart machine could be created. A smart machine is able to sense and adaptively react according to different production tasks. For example, if a specific processing job is assigned to a smart milling machine, it is able to select the available and suitable cutting tools and work out a production schedule given required quality standards and technical specifications.

2.2. Smart connection 连接

Smart machines should be connected so that they can collaboratively 合作 work. Smart connection layer uses various communication standards for this purpose. WiFi and BlueTooth may be used for vibration and force sensors which can real-time send the data to a central computer. Wired connection fashions like TCP/IP and RS232 are used for connecting machines, robots, and central computers. Radio waves are used for data transmission between RFID readers and tags. 4G is used for smart phones or handheld PDAs (Personal Digital Assitants).

Smart connection not only ensures the data communications 不仅智能设备之间可以交流 among different smart machines, but also allows a central 同时中央电脑可以对其进行控制 computer/server to control and manage various connection methods effectively and efficiently. By the assistance of smart connection, real-time manufacturing data could be captured and collected in a reliable way.

2.3. Data model 数据模型

In order to make full use of the captured and collected data, 完全使用捕捉到和收集到的数据 data model layer is responsible for processing 加工, classifying 分类 and standardizing various heterogeneous 标准化不同类型的数据 data into a formatted scheme. Thus, the formatted schemes could be further used for advanced decision-makings such as production planning and scheduling or real-time machine status monitoring. Based on the used sensors, this layer includes MTConnect data, STEP data model and XML data model. MTConnect uses industry standard to present process information from numerically controlled smart machine tools [23]. STEP data model is used for exchanging data among various information systems such as CAD, CAM, and product data management systems [24]. XML data model is used to organize a formatted data scheme so that further applications may use it for data sharing and exchanging under different situations [25].

This data model layer manages the data from smart machines via smart connection. After processing into a standardized format, these data could be accessed by cloud-based APPs which are designed and developed for different decision-makings in CMfg.

2.4. Smart view 智能显示终端

Smart view layer is designed as an end-user interface 用户终端界面 for visualizing various captured and collected data from manufacturing frontlines such as shop floors 工作车间. Three key views of data are included in this layer. Firstly, real-time machine status monitoring uses captured data from various sensors deployed on smart machines to graphically display the machine states. This view not only reflects the real-time working status of a smart machine, but also shows the sensed information like who is operating this machine, which component is being processed, etc. Secondly, statistics report uses collected historic data for generating various reports with a graphical approach, which includes bar charts, pie charts, and so on. Thus, end-users are able to check the periodical production history from these reports. Thirdly, an Augmented Reality (AR)-based visualization service is developed so that shop floor supervisors can use this service to monitor 监控智能工作单元 a working smart machine by integrating physical objects and their associated information through a visualized manner.

This layer converts the real-time captured data and historic information into various graphical fashions for facilitating the visibility of various manufacturing resources, especially working machines. Based on these views, users can make advanced decisions in terms of strategic and tactic resolutions.

These key layers are specifically designed for various end-users in a typical cloud manufacturing enterprise which maybe hierarchically organized. For example, a CEO (Chief Executive Officer) may use statistics report service to examine the production progresses via his/her smart phone. Customized views could be designed according to different applications and conditions such as peak season production planning and scheduling evaluations. On a manufacturing shop floor, a machine operator may use a RFID reader to assist him/her to accomplish daily operations [26]. Therefore, their decision-making procedures and operational flows could be reengineered and rationalized by the IoT-enabled solution.

3. A case study 个案分析

This section presents a case study for demonstrating how the proposed IoT-enabled real-time machine status monitoring solution facilitates the operations in a CMfg shop floor. This case is based on a laboratory testbed which is equipped with some typical manufacturing machines and assembly robots.

3.1. About the laboratory testbed

The laboratory testbed includes two milling machines 两个磨床 and two KUKA robots 两台KUKA机器人 which are placed in an area with around 20 m^2. There are several buffers for milling machines which are usually used for holding limited work pieces. Two robots are fixed and there are some conveyers that are responsible for moving various components. KUKA robots are used to pick up KUKA机器人通过终端来取传送带上合适的物件 suitable components for the final assembly.

Several challenges are faced when contemplating to monitoring the machine statuses on a real-time fashion. In the first place, there are large number of manufacturing resources 大量的制造资源 involved in the testbed, including machine tools, cutting tools, various materials, workers, and production orders. How to identify these resources systematically and effectively 如何系统和高效的识别资源 is a big issue. Secondly, how to facilitate the production operations or 如何促进产品操作和行为帮助 behaviors by the assistance of deployed IoT devices so that the real-time manufacturing data could be captured and collected? Thirdly, how to organize various heterogeneous data from different objects so that a visualized monitoring approach could be achieved? 如何组织不同层次的数据 来自不同对象

In order to address the above challenges, the following sections demonstrate the creation of a Cloud Manufacturing shop floor in the testbed and how to use the deployed IoT facilities to real-time monitor working machine statuses.

3.2. Creation of a Cloud Manufacturing shopfloor
云制造车间的创建

The creation of a Cloud Manufacturing shopfloor follows several steps which is shown in Fig. 2 upper section.

(1) Deployment of IoT devices. 物联网设备的调度 Various IoT devices are deployed in the testbed which is converted into a Cloud Manufacturing environment. Firstly, each machine tool like milling machine is equipped with a RFID tag so that it could be uniquely identified. 每一个铣床都可以被RFID识别 Work pieces such as raw materials, WIP items, and cutting tools are bound by RFID tags too. 不同物件也可以被RFID识别 Secondly, robots are equipped with RFID readers so that they can sense various components automatically. 机器人装有RFID阅读器 Thirdly, vibration sensors 刀具端装有震动传感器 are deployed on machine tools whose real-time working status could be obtained. Fourthly, each worker like machine operator or logistics operator carries a smart phone 每个操作人员带一个有NFC功能的智能手机 which has the functionality of NFC (Near Field Communication). This smart phone works as a RFID reader which is able to sense the manufacturing objects attached with RFID tags.

(2) Deployment of communication networks. 部署通信网络 Different communication networks are used for different purposes. NFC with 13.56MHz is used for communicating between smart phones and tags. The reading distance is about 20 cm. Wireless communication standards like Bluetooth is used for data transferring between smart phones and a central server. Wired networks with Ethernet, RS 232 and RS 485 are used for connecting KUKA robots and a computer so that their communications are ensured.

(3) Installation of designed system. 安装设计系统 An IoT-enabled real-time machine status monitoring platform is designed and developed as an entire solution for the testbed. This platform uses SOA-based implementation so as to achieve easy-to-deploy and simple-to-access fashions. The designed services are deployed in a cloud server 云服务器 which hosts the databases, 数据库 server-side applications 服务端应用 and all web services. 客户端服务 After that, the path for data models will be configured so that their accessibilities could be realized. Finally, client-side installations such as Java script, user's roles, authorities' settings and standardized connections are set up.

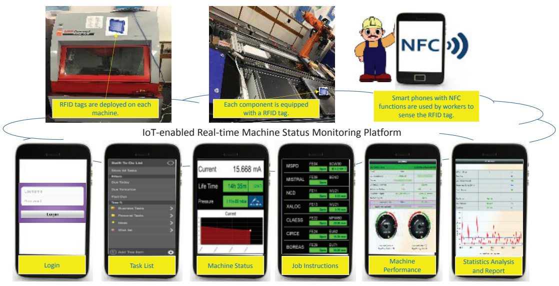

Fig. 2. Deployment of Designed Platform

3.3. Real-time machine status monitoring
机床实时状态监控

After the deployment of this platform, by the assistance of IoT facilities and developed services, real-time machine status monitoring could be achieved. Fig. 2 bottom section shows a typical machine operation based on the platform which rationalized the production operations and behaviors within the Cloud Manufacturing testbed. The operations follow several procedures:

(1) A machine operator uses his smart phone to download 机床操作员用智能手机下载服务端 the services. He uses the username and password to login his working dashboard where he is able to check 登录到自己的操作界面,检查任务和 the task assigned or historic production records.

(2) He selects one of the tasks from a job pool and the task associated information will be downloaded from the cloud. Thus, he can check the job instructions, technical figures, quality criteria, etc. 从任务池中下载一个任务 查看详细信息

(3) He approaches the assigned machine and uses his smart phone to detect the tag deployed on the machine for indicating the attendance. (*A time stamp shows who uses this machine at what time*). 用手机感知指定的机床 时间戳显示机器使用时间 人

(4) After the attendance, some critical information such as required cutting tools and materials will be sent to him 刀具 材料信息从云端发送给他 from the cloud. He uses his smart phone to sense the required items from specific locations and picks up them for the task. (*A time stamp and location data record who uses what at what time and why*.)

(5) He installs the cutting tools with vibration sensors attached on the machine and fixes the work piece by clicking a button on the mobile APP. (*The information about who is processing what by which machine at when will be recorded*.)

(6) After the processing, he presses a button on the APP to inform the completion of a task. Another task will be updated on his smart phone instantly.

(7) The finished work piece will be sent to robotic assembly work-station. A worker uses his smart phone to detect the work piece and places on the conveyer. (*The work piece movement information will be recorded like who moves what from where at what time.*)

(8) Finally, the robots can detect the required work piece and pick up for final assembly through IoT facilities.

Within the Cloud Manufacturing environment, the previous mentioned challenges in the testbed are addressed. Crucial production data are captured and collected accordingly. Two types of information are critical. First is the IoT-enabled manufacturing objects whose operations and behaviors are clearly identified and captured. Such data could be used for evaluating various performance and generating statistics analysis reports. Second is the real-time cutting tool status, specifically vibration information in this paper. Using this data, the real-time machine vibration status could be monitored. These two types of data are graphically organized using some smart web components for end-users. For example, machine statuses like starting time, vibration, current, and processing tasks could be visualized by date char, curves, and bar chart. By making full use of the historic data, machine performance could be achieved based on a dashboard view. Finally, the ‘5w’ questions could be answered by the proposed platform.

4. Conclusions

This paper introduces an IoT-enabled real-time machine status monitoring approach for Cloud Manufacturing. Machine tools, as one of the key shared resources in CMfg, should be real-time monitored. By making full use of IoT technology, various manufacturing resources are identified and their statuses could be then captured. The real-time reflection of their statuses may be used for sharing among different manufacturing parties, which is able to achieve ultimate service sharing and circulating under CMfg.

Several contributions from this research are significant. Firstly, a SOA architecture 面向服务架构 for organizing a CMfg shop floor is presented. The hierarchical architecture not only clearly identifies the manufacturing objects at different layers, but also presents a feasible implementation framework for companies, especially small and medium-sized enterprises, who are contemplating CMfg in the future. Secondly, a systematic deployment scheme for IoT facilities in a typical manufacturing shop floor is demonstrated. Key stations and components are bound by IoT devices according to their production behaviors. Workers and robots are equipped with RFID readers so that they can detect various objects which are tagged because they are key value-adding points and decision-makers within CMfg. Thirdly, re-engineered and rationalized production operations under CMfg environment are presented so that end-users may follow the steps for getting benefits from the proposed solution. Insights like key information for each step could be referenced by practitioners when they are trying the IoT-enabled solutions in their manufacturing shop floors in the future upgrading by CMfg.

Several future research should be also considered. This paper only presents the typical rationalized operations. How to build up a behavioral model so that various manufacturing objects could be shared using standardized scheme needs to be further studied. Moreover, decision-makings within an IoT-enabled CMfg are totally different from traditional manufacturing. How to made production optimizations based on the real-time data is another research direction. Finally, IoT devices and deployed sensors may generate enormous data along with the production processes. How to fully use these data for manufacturing analytics such as quality analysis, performance evaluations, market prediction, etc is indeed an invaluable research topic.

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