Available online at www.sciencedirect.com

ScienceDirect

Procedia CIRP 56 (2016) 372 – 377

www.elsevier.com/locate/procedia

9th International Conference on Digital Enterprise Technology - DET 2016 – "Intelligent Manufacturing in the Knowledge Economy Era

A Cyber-physical System Architecture in Shop Floor for Intelligent Manufacturing

Chao Liu, Pingyu Jiang*

State Key Laboratory for Manufacturing Systems Engineering, Xi'an Jiaotong University, Xi'an, 710054, China

* Corresponding author. Tel.: +86-029-83395396; fax: +86-029-83395396. *E-mail address:* pjiang@mail.xjtu.edu.cn

Abstract

A Cyber-physical System (CPS) architecture in shop floor is proposed for achieving the goals of intelligent manufacturing. The proposed architecture provides a guideline to construct a CPS system from the hardware interconnection, to the data acquisition, processing, and visualization, and the final knowledge acquisition and learning. Furthermore, three key enabling technologies are discussed, *i.e.*, interconnection and interoperability among different devices, industrial big data analysis for production process management and control, and intelligent decision-making based on knowledge acquisition and learning methodology. Finally, a CPS added on a small-scale flexible automated production line in our Micro Manufacturing System Lab is taken as an example to verify the feasibility of proposed CPS architecture.

Peer-review under responsibility of the scientific committee of the 5th CIRP Global Web Conference Research and Innovation for Future Production

Keywords: cyber-physical system; intelligent manufacturing; industrial big data; knowledge learning

1. Introduction

During the past decade, the rapid advancement of Information and Communication Technologies (ICT) has boosted the development of advanced sensors, data acquisition system, wireless communication devices and distributed computing solutions. Such technologies are integrated into a new system called Cyber-physical System (CPS). CPS is a system of collaborating computational entities which are in intensive connection with the surrounding physical world and its on-going processes, providing and using, at the same time, data-accessing and data-processing services available on the internet [1]. CPS has caught ever-growing attentions of researchers from academia, industry, and government in recent years. Currently, a precursor generation of CPS can be found in areas as diverse as aerospace, automotive, civil infrastructure, chemical processes, energy, healthcare, transportation and manufacturing [2].

As a technology base for building intelligent manufacturing environment, CPS is introduced into the shop floor, providing factories with continuous production, near-zero downtime and intelligent decision-making in manufacturing process [3]. In such an intelligent manufacturing shop floor, machine tools and their auxiliaries, industrial robots, Automatic Guided Vehicles (AGVs) and staffs constitute the manufacturing resources (physical space). Manufacturing data is collected from the sensors/RFID devices/measurement devices deployed on these manufacturing resources, which constitute the cyber space. Often, a communication channel is involved to transmit data that are used to monitor and control the manufacturing resources. On the cyber side, computations are carried out with the objective of achieving high quality, flexible production and reduced cost, based on which intelligent decisions are taken and the manufacturing resources are adaptively controlled. Thus, the expectations on self-awareness and self-maintenance of manufacturing resources, and intelligent adaptive control of manufacturing processes can be realized by integrating CPS with production, logistics as well as industrial services [4, 5].

According to Dwnrschak and Zaiser' survey [6], the degree of CPS implementation in manufacturing enterprises has been fairly low, so it is essential to put forward a universal architecture as a step-by-step guideline for developing and configuring a CPS for shop floor. However, several challenges

Peer-review under responsibility of the scientific committee of the 5th CIRP Global Web Conference Research and Innovation for Future Production
doi:10.1016/j.procir.2016.10.059

exist in the development of CPS [7]. For example, to enable seamless integration between cyber space and physical space, the events occurred in the physical space need to be reflected in the cyber space, and the production commands given by the cyber space need to be communicated to the physical systems. Both these actions need to be accurately performed and in a timely manner. Furthermore, sensors (*e.g*., force, vibration) monitoring manufacturing processes that work at high sampling rates can generate a large amount of data within a short time period. However, many manufacturing systems are not ready to manage big data due to the lack of smart analytic tools [2].

To address the issues mentioned above, a CPS architecture in shop floor for intelligent manufacturing is proposed in this paper, and then three key enabling technologies are considered for CPS implementation, *i.e.*, (1) interconnection and interoperability among heterogeneous devices which ensure the real-time data acquisition from production environment and production commands feedback from the cyber space; (2) management, analysis of multi-source and heterogeneous big data; (3) knowledge acquisition and learning methodology that supports intelligent decision-making. Finally, a CPS added on a small-scale flexible automated production line in our Micro Manufacturing System Lab is taken as an example to verify the feasibility of proposed CPS architecture.

2. CPS architecture for intelligent manufacturing

Fig.1 depicts a CPS architecture in shop floor for intelligent manufacturing and it includes three layers, *i.e.*, physical connection layer, middleware layer and computation layer. The explanation of each layer is presented as follows.

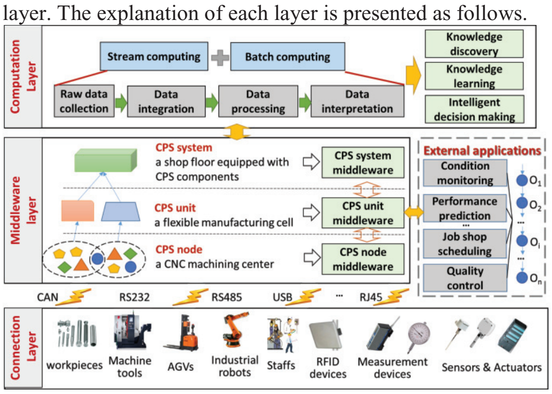

Fig. 1. CPS architecture for intelligent manufacturing.

2.1. Physical connection layer

Sensors are the machine's gateway to sense its surrounding physical environment. Using appropriate sensor installation, various signals such as vibration, pressure, temperature can be extracted. So the first step of CPS implementation in shop floor is to embed components like sensors, RFID devices and measurement devices on the manufacturing resources and distribute them in the production environment. Then a group of machines are connected with each other through fieldbus technology and/or industrial Ethernet. In this layer, issues about protocol, processing, location, distance, and storage need to be considered when the embedded component is chosen. For example, the uniform and robust connections between heterogeneous physical entities (*e.g*., manufacturing resources, sensors, actuators, and measurement devices) should be defined; proper sensors (type and specification) should be selected and deployed on proper locations with low cost and high efficiency on the basis of historical machining tasks.

2.2. Middleware layer

This layer aims to transfer the data collected from the embedded components to the central server for analysis, and send the production commands given by computation layer or external applications (*e.g*., condition monitoring, dynamic job scheduling, and quality control) to controllers for control. Therefore, CPS middleware acts as a bond among physical connection layer, computation layer and external applications. According to the above descriptions, the middleware must support the following functions:

Device management. Different external applications are likely to use different sensors/RFID devices/measurement devices which have different brands and types. Moreover, these devices have their own communication protocols and standards. Thus, a public device management module is needed to drive these multiple devices work together, and eventually achieve the goal of plug and play.

Interface definition. The data interface provides a channel for CPS node communications, and required data/information to the computation layer and external applications, hiding all the details of diversity.

Data management. The data collected from sensors/RFID devices/measurement devices can be production environment state (e.g., temperature, humidity, and noise), machine working condition (e.g., power, speed, and vibration), workpiece state and quality data (e.g., location, size, roughness, and tolerance), etc. The potentially large variety of data types and formats necessitates a uniform data format and data exchange standard to manage data in context with process-related information in the shop floor.

2.3. Computation layer

A large amount of data, real-time online or historical offline, is gathered by various sensors/RFID devices/measurement devices, or obtained from Enterprise Information Systems (EIS) such as ERP, MES, and SCM. Specific models, algorithms and tools have to be used to extract underlying patterns that provide better insight over machine working conditions, workpiece quality, manufacturing processes, *etc*. Take job shop scheduling as an example, the dispatching rules are incorporated with the data obtained from online measurement, data processing, or data fusion, which makes sense especially when machines works in a complex production environment and undergoes a different deterioration rate. In this layer, two forms of big data computing that need to be addressed are batch computing and stream computing. Batch computing is used to process large