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A Cyber-Physical Systems architecture for Industry 4.0-based manufacturing systems

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Abstract

Recent advances in manufacturing industry has paved way for a systematical deployment of Cyber-Physical Systems (CPS), within which information from all related perspectives is closely monitored and synchronized between the physical factory floor and the cyber computational space. Moreover, by utilizing advanced information analytics, networked machines will be able to perform more efficiently, collaboratively and resiliently. Such trend is transforming manufacturing industry to the next generation, namely Industry 4.0. At this early development phase, there is an urgent need for a clear definition of CPS. In this paper, a unified 5-level architecture is proposed as a guideline for implementation of CPS.

Keywords: Cyber-Physical System; Industry 4.0; Health management and prognostics; Time machine

1. Introduction

Cyber-Physical Systems (CPS) is defined as transformative technologies for managing interconnected systems between its physical assets and computational capabilities [1]. With recent developments that have resulted in higher availability and affordability of sensors, data acquisition systems and computer networks, the competitive nature of today's industry forces more factories to move toward implementing high-tech methodologies. Consequently, the ever growing use of sensors and networked machines has resulted in the continuous generation of high volume data which is known as Big Data [2,3]. In such an environment, CPS can be further developed for managing Big Data and leveraging the interconnectivity of machines to reach the goal of intelligent, resilient and self-adaptable machines [4,5]. Furthermore by integrating CPS with production, logistics and services in the current industrial practices, it would transform today's factories into an Industry 4.0 factory with significant economic potential [6,7]. For instance, a joint report by the Fraunhofer Institute and the industry association Bitkom said that German gross value can be boosted by a cumulative 267 billion euros by 2025 after introducing Industry 4.0 [8]. A brief comparison between current and Industry 4.0 factories is presented in Table 1 [9].

Since CPS is in the initial stage of development, it is essential to clearly define the structure and methodology of CPS as guidelines for its implementation in industry. To meet such a demand, a unified system framework has been designed for general applications. Furthermore, corresponding algorithms and technologies at each system layer are also proposed to collaborate with the unified structure and realize the desired functionalities of the overall system for enhanced equipment efficiency, reliability and product quality.

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2. CPS 5C level architecture

The proposed 5-level CPS structure, namely the 5C architecture, provides a step-by-step guideline for developing and deploying a CPS for manufacturing application. In general, a CPS consists of two main functional components: (1) the advanced connectivity that ensures real-time data acquisition from the physical world and information feedback from the cyber space; and (2) intelligent data management, analytics and computational capability that constructs the cyber space. However, such requirement is very abstract and not specific enough for implementation purpose in general. In contrast, the 5C architecture presented here clearly defines, through a sequential workflow manner, how to construct a CPS from the initial data acquisition, to analytics, to the final value creation. As illustrated in Fig. 1, the detailed 5C architecture is outlined as follows:

2.1. Smart connection

Acquiring accurate and reliable data from machines and their components is the first step in developing a Cyber-Physical System application. The data might be directly measured by sensors or obtained from controller or enterprise manufacturing systems such as ERP, MES, SCM and CMM. Two important factors at this level have to be considered. First, considering various types of data, a seamless and tether-free method to manage data acquisition procedure and transferring data to the central server is required where specific protocols such as MTConnect [10] and etc. are effectively useful. On the other hand, selecting proper sensors (type and specification) is the second important consideration for the first level.

2.2. Data-to-information conversion

Meaningful information has to be inferred from the data. Currently, there are several tools and methodologies available for the data to information conversion level. In recent years, extensive focus has been applied to develop these algorithms specifically for prognostics and health management applications. By calculating health value, estimated remaining useful life and etc., the second level of CPS architecture brings self-awareness to machines (Fig. 2).

Table 1
Comparison of today's factory and an Industry 4.0 factory.

	Data source	Today's factory		Industry 4.0	
		Attributes	Technologies	Attributes	Technologies
Component	Sensor	Precision	Smart sensors and fault detection	Self-aware Self-predict	Degradation monitoring & remaining useful life prediction
Machine	Controller	Producibility & performance	Condition-based monitoring & diagnostics	Self-aware Self-predict Self-compare	Up time with predictive health monitoring
Production system	Networked system	Productivity & OEE	Lean operations: work and waste reduction	Self-configure Self-maintain Self-organize	Worry-free productivity

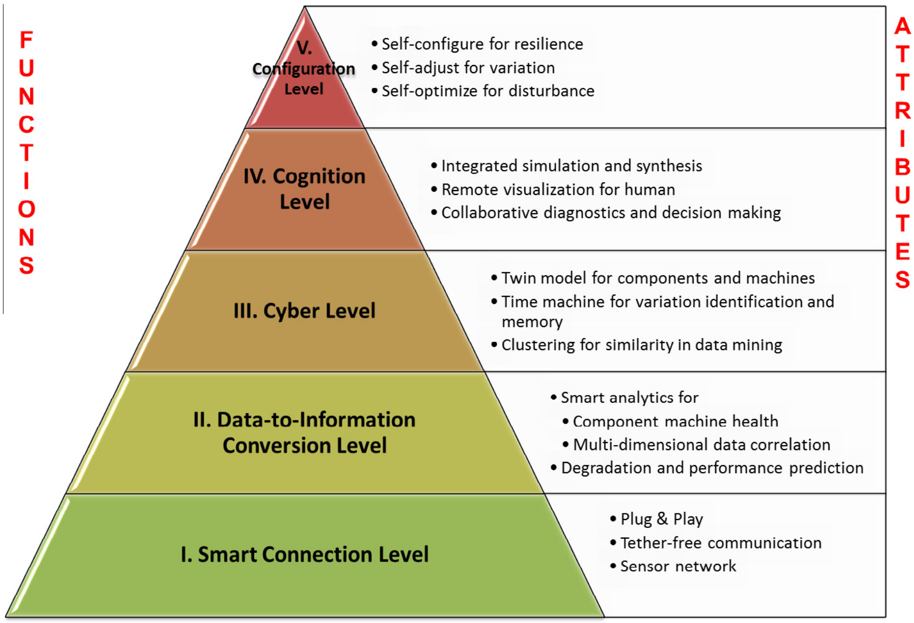

Fig. 1. 5C architecture for implementation of Cyber-Physical System.