A Comprehensive Overview of Cyber-Physical Systems: From Perspective of Feedback System

Xinping Guan, *Senior Member, IEEE*, Bo Yang, *Member, IEEE*, Cailian Chen, *Member, IEEE*, Wenbin Dai, *Member, IEEE*, and Yiyin Wang, *Member, IEEE*

***Abstract*—Cyber-physical systems (CPS) are characterized by integrating cybernetic and physical processes. The theories and applications of CPS face the enormous challenges. The aim of this paper is to provide a latest understanding of this emerging multi-disciplinary methodology. First, the features of CPS are described, and the research progresses are summarized from different components in CPS, such as system modeling, information acquisition, communication, control and security. Each part is also followed by the future directions. Then some typical applications are given to show the prospects of CPS.**

***Index Terms*—Cyber-physical systems (CPS), system modeling, information acquisition, communication, control, security.**

I. Introduction

In the last decade, the academia and industry have witnessed the flourishing research activities on cyber-physical systems (CPS). CPS are defined as the systems by integrating computation, networking, and physical processes, where the embedded computers and networks control and monitor and physical processes usually in a closed-loop while the latter affects the computations and even the networks. It should be noted that the integration does not mean the simple convergence of the physical world and the cyber space, but the physical and cyber components are deeply interacted. Therefore, the analysis and design of CPS is based on the understanding of the joint dynamics of physical processes, computer, software and networks.

Many systems can be categorized as CPS, such as demand response in smart grids[1−3], where the demand side users, such as various domestic appliances constitute the physical components, and the data of demand load are collected by the smart meters, which connect the physical world and the cyber space. The demand load data are transferred via the two-way communication channels that are used to measure and control the physical component. On the cyber side, the computations are carried out by the independent system operator (ISO) with the objective of utility maximization of user sides and cost minimization of user side, and a suitable real-time electricity price is announced, based on which the demand side (physical components) are further controlled. Another example is the body sensor network, which is a network of medical devices that can sense medical or physiological data, which can be used to augment bodily functions through drug delivery or support for the movement of prosthetic limbs[4]. A multi-agent system such as multiple autonomous underwater vehicles (AUVs) can be also seen as CPS whose sensors and networking system enable AUVs to monitor their location and operation while coordinating with each other to tracking a moving target. Thus, CPS range from miniscule such as body sensors to large scale such as power grid. The study on CPS can provide a comprehensive and inter-disciplinary framework for analyzing and designing these practical systems.

CPS shares some common features with the current popular information and communications technology (ICT) systems, namely embedded systems, networked control systems (NCSs), internet of things (IoT) and industrial internet. We list the comparisons in chronological order and state the relationship between CPS and other emerging technologies.

1) CPS are not the generic embedded systems or NCSs. It can be regarded as a networked embedded systems.

2) CPS are not IoTs, although they are sometimes used interchangeably. IoT is usually corresponding to a hierarchical communication infrastructure that has information sensing, processing and transmission functionalities in an application-driven way. While CPS emphasize the interaction between physical processes and cyber dynamics. IoT is more like a platform for implementing some applications. In another word, it can be regarded as an extension of internet. Contrasting with IoT, CPS is a way of understanding and designing real world.

3) The forthcoming industrial internet refers to the integration of the global industrial ecosystem, pervasive sensing, advanced computing and ubiquitous network connectivity that enables the increasing benefits of world economy[5]. Thus it can be seen that its technological basis is CPS.

Due to the tight coupling and coordination between cyber and physical worlds, CPS are dynamically reorganizing and reconfiguring control systems with high degree of automation at multiple spatial and temporal dimensions. To enable seamless integration, the implementation of CPS relies on the closed-loop consideration and design of the whole system. As shown in Fig. 1, the events sensed in the physical processes need to be

Manuscript received May 6, 2015; accepted August 18, 2015. This work was supported by National Natural Science Foundation of China (61221003, 61174127, 61573245, 61273181, 61503247, 61301223), and Shanghai Municipal Science and Technology Commission (15QA1402300, 14511107903). Recommended by Associate Editor Youxian Sun.

Citation: Xinping Guan, Bo Yang, Cailian Chen, Wenbin Dai, Yiyin Wang. A comprehensive overview of cyber-physical systems: from perspective of feedback system. *IEEE/CAA Journal of Automatica Sinica*, 2016, **3**(1): 1−14

Xinping Guan, Bo Yang, Cailian Chen, Wenbin Dai, and Yiyin Wang are with the Department of Automation, Shanghai Jiao Tong University, and Key Laboratory of System Control and Information Processing, Ministry of Education of China, Shanghai 200240, China (e-mail: xpguan@sjtu.edu.cn; bo.yang@sjtu.edu.cn; cailianchen@sjtu.edu.cn; w.dai@sjtu.edu.cn; yiyinwang@sjtu.edu.cn).

Color versions of one or more of the figures in this paper are available online at http://ieeexplore.ieee.org.