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Review of Cyber-Physical System

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Abstract

This article describes the Cyber-Physical System (CPS), analyzes the current development situation of CPS from the architecture, researches and summarizes the development trend of CPS, and introduces the application status of this technology in various fields.

Keywords

Cyber-Physical System, CPS, Architecture, Smart lighting.

1. Introduction

The Cyber-Physical System (CPS)[1] is a large and complex system theory that integrates the development of multi-disciplinary technology and integrates communication, sensing, computing, and control theories. The cyber-physical system has been widely concerned since it was proposed by the National Natural Science Foundation in 2006. It uses a series of computing units to deeply integrate and interact with physical objects in a network environment, improving the system's capabilities in information processing, real-time communication, remote precise control, and autonomous component coordination[2]. Compared with real-time embedded systems and network control systems, CPS has advantages in real-time sensing and dynamic monitoring in large-scale complex systems, with better flexibility, higher intelligence, and more efficient processing capabilities. The applications of CPS include the fields of smart city construction, autonomous vehicles, energy management systems, industry 4.0 smart manufacturing, and healthcare[3]. Studying the CPS technology and its development trend that can be used to build a smart system in the future is the basis for building a smart life for humans in the future. The cyber-physical system is expected to set off a new wave of technology after the computer and the Internet[4].

2. Analysis of CPS Architecture

Academician Ji-feng He of East China Normal University believes that the core concept of CPS can be summarized as 3C[5] (Computation, Communication, Control). CPS deeply integrates computing, network communication and control equipment, so that objectively existing things have the ability to autonomously calculate. As a large and complex hybrid autonomous system, it has the characteristics of real-time response, fault tolerance, and high security[6].

CPS is a system that integrates computing, communication, and control, and deeply integrates computing data and the physical world[2]. Its architecture is also a hub that connects the physical world and data in the system. The basic architecture of CPS includes three layers, which are the physical layer, the network layer, and the information layer from bottom to top. These three layers ensure the CPS, which senses the environment from the physical hardware, passes information to the

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information processing and decision-making components through information transmission, and then changes the physical hardware cycle through decisions and commands. as shown in Figure 1.

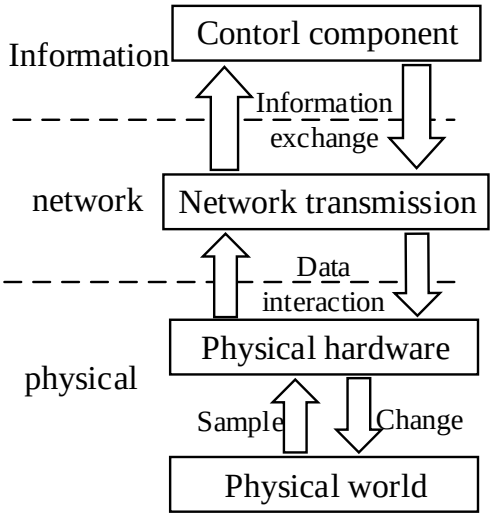

Figure 1.CPS basic architecture

CPS architecture changes during the design and research process with changes in application scenarios, changes in requirements, and changes in consideration. In reference [7] and reference [8], a five-level CPS architecture is adopted for building environmental control systems and smart corridor systems, and the information layer is divided into a calculation layer, a control layer, and a service layer. Reference [9] uses a library intelligent lighting CPS composed of five units, which are respectively an application unit, a network unit, a calculation unit and a control unit, and a perception unit from top to bottom. Reference [10] proposed an architecture of multi-level processors based on event-driven CPS. When the low-level processors cannot process the information, the information is passed from the low-level to the high-level, until the central processor processes the event with the highest authority. Reference [11] proposed an overall framework for a smart factory, consisting of a physical system layer, a network system layer, and a human system layer. In reference [12], a MSIA (Mobile Sensor Information Agent) was added to the architecture to improve the stability, robustness, and efficiency of mobile sensor data processing in CPS. Reference [13] proposed a 5C architecture of CPS, including Connection, Conversion, Cyber, Cognition, and Configuration. Reference [14] proposed a typical CPS hierarchical architecture, including five hierarchical structures, as shown in Figure 2 below.

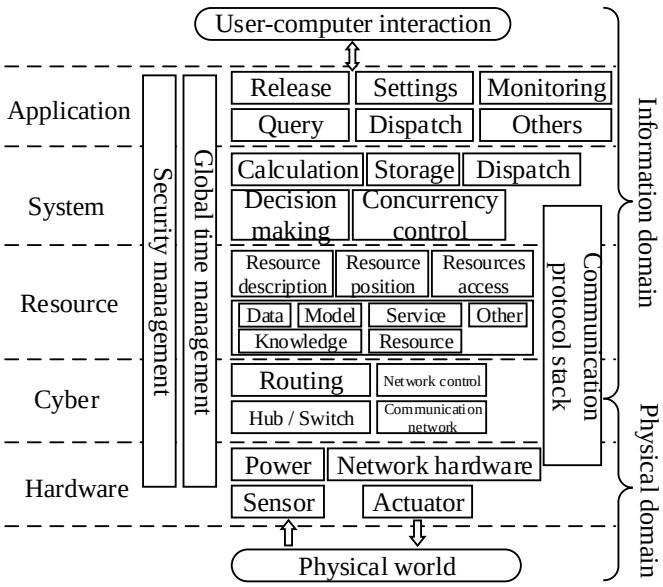

Figure 2.Typical architecture of CPS

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The hardware layer includes sensors, actuators, and hardware, corresponding to the physical layer; the network layer completes information transmission and corresponds to the network layer; the resource layer, system layer, and application layer complete data storage and processing, information analysis and application integration, corresponding to Information layer.

Whether it is a basic architecture or a typical architecture, its purpose is to achieve the functions of each structure in the CPS. The former has higher universality and flexibility in simpler systems, and the latter is more suitable for complex systems. By refining each part, the system has higher design and implementation and functional maintenance. Feasibility, while ensuring the independence and connection of each level through the network. From the foregoing references, it can be found that in the application process of CPS, the typical architecture is the mainstream of current research, which is more in line with the actual development needs, and has higher practicality and uniformity in the architecture.

3. Trend of development

With the deepening of the application and research of CPS systems, scholars are exploring a unified method or architecture in CPS that can be used for different types of modeling. Reference [15] proposed a structured, descriptive behavior heterogeneous component model that solves the problem of computing model differentiation. First, the unified component is used for modeling, and then the XML (Extensible Markup Language) specification is used to describe various components. Verification is performed through co-simulation. This modeling method can solve the problem of inconsistency and non-extensibility of description language.

Through the interaction between the network and the physical system, CPS builds a physical and information space that is connected by driving data, thereby realizing the optimal allocation of real resources. The terminal system of CPS is usually a traditional centralized tightly coupled embedded computing system, which contains a large number of physical systems composed of intelligent wireless sensor networks[16]. However, with the development and research of CPS, it will develop towards the following characteristics.

3.1 Based on physical system

Physical system is an important part of CPS[17]. The purpose of the cyber-physical system is to scientifically regulate the target through the physics department. Whether it is system data acquisition or system execution instructions to change the physical world, the support of the physical system is indispensable. The physical system is the most basic structure of CPS, and it is also an important foundation for building CPS. Physical systems are research objects that involve multiple fields, including system design, hardware design, energy management, hardware size, connectivity, network design, etc.[16]

3.2 Data as the core

The role of the information system is to transform the information obtained by the physical system in the system into rules and models of the software system. The main input of an information system is data. The operation process is the use of data. The output is the calculation of the data. The means of verification also rely on the data, so data is the absolute core of the information system. At the same time, CPS is a data-driven system. It needs to make full use of information systems in operation.

3.3 Combination of virtual and real

CPS is a kind of intelligent control system with deep integration of virtual (information space) and real (physical space)[18]. CPS establishes the digital twins[19] that can reflect the true state of the device at the data level. Data exchange is used to ensure the communication between the digital twins and the models established in the physical space, so that the twins have the ability to perceive, analyze, make decisions and execute ability. Through the process of combining reality with reality, further optimize the ability of CPS in the optimization of system resource allocation.

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3.4 Heterogeneity and distribution coexist

CPS is the product of the integration of heterogeneous distributed systems. It has the deep integration and interaction of information systems and physical systems, and can handle the time synchronization and control position of different components. Different systems have very different networks and architectures. Integrating them in CPS will inevitably lead to heterogeneity.

3.5 Openness and security coexist

CPS is a huge system that can integrate a variety of systems and functions. The system and system, and functions and functions can achieve mutual coordination and common operation through data connections. In terms of perspective, CPS is open and allows the integration of system functions. At the same time, the application fields of CPS are those with extremely high security requirements. The system needs reliability and security, so CPS also has security.

3.6 High degree of system autonomy

CPS is a system for rational scheduling and configuration of limited resources. For a large number of objects, the system needs real-time supervision and control. Throughout the entire supervision and control process, CPS actively senses changes in objects, changes in the environment, and changes in equipment status through the physical system, and analyzes relevant information in real time to make appropriate responses to changes[8].

4. Status of application

Once CPS was proposed, it attracted widespread international attention: Whether it is the "Advanced Manufacturing" strategy in the United States, the "Industry 4.0" strategy in Germany, or the "Made in China 2025" strategy in China, CPS is taken as an important field and core technology. China also proposes: "Intelligent equipment based on cyber physical systems Manufacturing industries such as smart factories are leading the transformation of manufacturing methods "[20,21]. It is precisely because CPS has the characteristics of closely linking computing data with the physical world that it can be widely used in various intelligent systems.

According to the development trend of CPS, it can be seen that in recent years, CPS has been in the process of rapid development, and has promoted automobiles, industrial automation, medical care, emergency response, industrial control systems, intelligent buildings, smart roads, and intelligent transportation systems. And key developments in power, power systems, and other areas [22]. Reference [3] explained the application fields of distributed CPS integrating cloud computing, fog computing, and edge computing, and pointed out that adopting more flexible distributed computing is both a challenge and a great opportunity. Reference [23] discussed the application feasibility of the Zig Bee technology of the Internet of Things in CPS, and pointed out that the application of traditional Internet of Things technology in CPS can speed up the application process of CPS. CPS has certain prospects both in the application of emerging technologies and the re-application of traditional technologies.

Although the current application fields of CPS are mainly industrial[24,25,26], power system[27] and other fields, many experts and scholars still carry out a lot of research in other fields. In the research of the building management system, reference [7] pointed out that the characteristics of CPS matched the technical requirements of building environmental control, and proposed a control scheme for air conditioning equipment of building environmental control system; In the field of smart city construction, reference [8], reference [28], and reference [29] respectively studied the corridor system in the city, the waste transfer dispatching system in the city, and the smart city management system, and pointed out that facing smart cities Complex systems in the construction field, and the full use of CPS application characteristics can better solve related problems; In the field of agricultural management, reference [30]] applied the powerful sensing and communication capabilities of CPS to the precise control of greenhouse control systems to further improve the level of precision of agricultural management systems. Reference [31] improves vehicle-to-vehicle (V2V) communication

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performance by linking V2V communication characteristics with the physical movement characteristics of vehicles. Reference [32] uses the information physical social system formed by CPS and society to solve intelligent traffic management; in medical treatment In the field of health, the Reference [33] researched the medical health monitoring system based on CPS, pointing out that CPS still has certain application prospects in this field.

5. Research and Prospect

It can be found from the application status that CPS has received a lot of attention from experts and scholars due to its own development potential and characteristics, and its application field is also expanding rapidly. From the architecture and development trend of CPS, it can be found that CPS is suitable for complex large-scale control systems. As an important part of city management, lighting management can also adopt CPS theoretical techniques. Reference [9] proposed the theoretical structure of the intelligent lighting system of the library based on CPS, and pointed out that the application of CPS system for related design can further optimize the use experience and reduce energy consumption.

The intelligent lighting system based on CPS is the result of applying the theoretical characteristics and technical advantages of CPS to the field of intelligent lighting. This paper proposes a smart lighting CPS architecture, as shown in Figure 3 below.

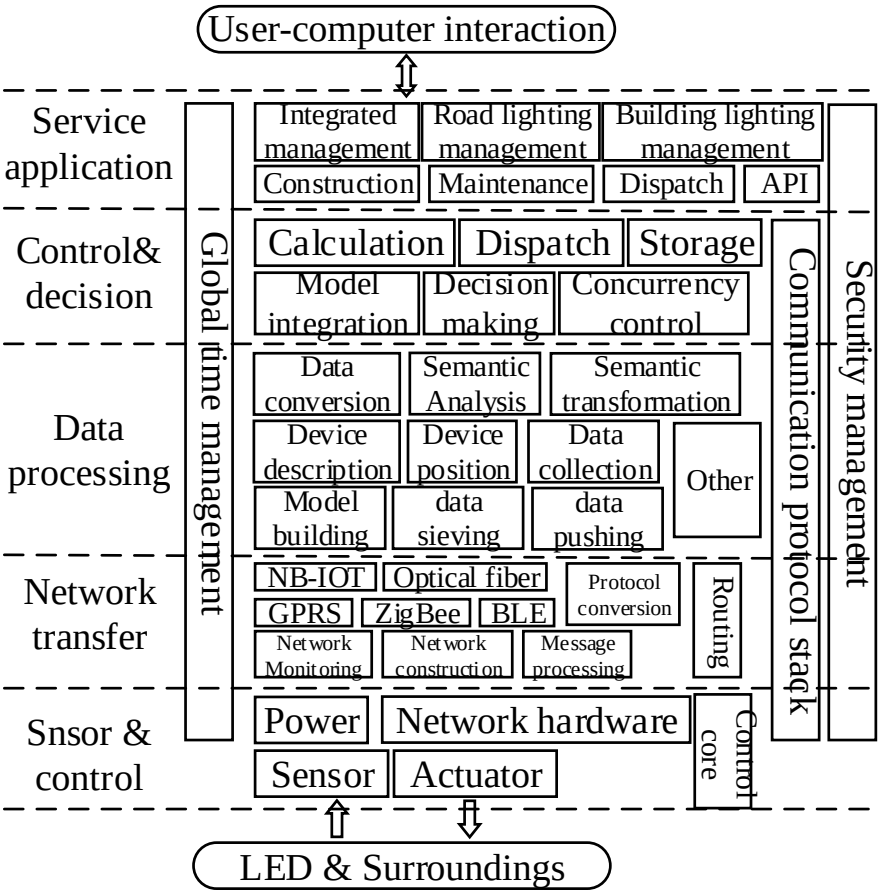

Figure 3.Architecture of smart lighting CPS

It combines the theoretical technology and design ideas of CPS and smart lighting technology, and uses integrated automation technology to achieve automatic control and remote monitoring of various devices in the lighting system in the city. At the same time, the Internet of Things technology is used to realize the ubiquitous perception of people, things and the environment near the lighting device. The smart lighting platform can not only utilize integrated automation systems and Internet of Things technologies, but also make up for the shortcomings of both technologies. The intelligent lighting

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platform based on CPS improves the integration of lighting system perception, communication, calculation and control through multi-level data processing, decision control and information interaction, so that the platform itself has better openness, heterogeneity and distribution. And improve the level of intelligence.

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