Chapter 2
Latest Advancement in CPS and IoT Applications

2.1 Introduction

Internet of Things (IoT), as one of the most important new information technologies, has attracted great attention from governments, industries, and academia, and has been widely used in many fields, such as production, healthcare, and logistics. Originated from the radio frequency identification (RFID) systems, the term IoT was first coined by Ashton in MIT Auto-ID Labs in 1999 [1], referring to wireless communication abilities integrated with sensors and computing devices, thus enabling uniquely identifiable *things* to provide data over the Internet with limited or no human interaction. With the new information technologies integrated with IoT, it is hard to define IoT clearly and uniformly, especially its various application backgrounds. For brevity, IoT can be understood from two perspectives, which are "Internet-oriented" and "Things-oriented" [2]. The former can be viewed as the expansion of Internet applications. IP stack that already connects a huge amount of communicating devices, has all the qualities to make IoT a reality, while the latter means that a large number of *things*, which have identities and virtual personalities, form a worldwide network based on standard communication protocols [3]. In general, the architecture of IoT can be divided into four layers, i.e. sensing layer, networking layer, middleware layer, and application layer. The sensing layer is responsible for sensing and capturing the real-time information of resources, devices, and further sharing among the identified units through a constructed wireless network with tags and sensors. The networking layer is to connect all things together to form the physical network of manufacturing systems, and allow things to share the information with other connected things. The middleware layer is to manage, control, and transmit information in real time through a cost-efficient platform integrated by hardware and software functions. The main function of application layer is to integrate the methodologies and functions of the system to achieve IoT-enabled industrial applications (such as remote monitoring of robots, tracking and tracing of manufacturing resources in real time), and IoT-enabled

L. Wang and X. V. Wang, *Cloud-Based Cyber-Physical Systems in Manufacturing*,
https://doi.org/10.1007/978-3-319-67693-7_2

manufacturing systems. Within the powerful functionality, IoT is widely applied in a number of industries [2], and these applications include four main domains: (1) transportation and logistics, including assisted driving, mobile ticketing, monitoring environmental parameters, augmented maps, and so on; (2) healthcare, including tracking, identification and authentication, data collection, sensing, and others; (3) smart environment (home, office, and plant), such as comfortable homes and offices, smart building, smart cities, smart factories, smart museums, and so on; and (4) personal and social domain, including social networking, historical queries, losses, thefts, and so forth.

In the past decades, advancements in Web- and Internet-based systems and applications have opened up the possibility for industries to utilise the cyber workspace to conduct efficient and effective daily collaborations from anywhere in distributed manufacturing environments [4]. Recent advances in manufacturing industry have paved way for a systematic deployment of Cyber-Physical Systems (CPS), within which information from all related perspectives is closely monitored and synchronised between the physical factory floors and the cyber computational space. CPS are engineered systems that are built from and depend upon the seamless integration of computational algorithms and physical components [5]. The term *Cyber-Physical Systems* was first proposed in the US in 2006 [6]. With the wide applications and development of CPS, the definition of CPS is multiple, and not clear and unified. For example, CPS are integrations of computation and physical processes. Embedded computers and networks monitor and control the physical processes, usually with feedback loops where physical processes affect computations and vice versa [7]. In other words, CPS use computations and communication deeply embedded in and interacting with physical processes so as to add new capabilities to physical systems [1]. Unlike traditional embedded systems that are typically standalone, a full-fledged CPS is characterised by a network of interacting elements with physical input and output, resembling the structure of a sensor network. Tremendous progress has been made in advancing CPS technology over the last five years. Certainly, new smart CPS will drive innovation and competition in sectors as diverse as aerospace, automotive, chemical process, civil infrastructure, energy, healthcare, manufacturing, transportation, and so forth. One example of CPS is an intelligent manufacturing line, where a machine can perform a variety of processes by communicating with the components. Ongoing advancement in science and engineering will continue to enhance the link between computational and physical elements, dramatically increasing the adaptability, autonomy, efficiency, functionality, reliability, safety, and usability of CPS [5]. The final aim of CPS is to realise "intelligent monitoring" and "intelligent control" [8, 9]. These are the processes that need to realise real-time information extraction, data analysis, decision making and data transmission. CPS is an emerging discipline and has attracted and engaged many researchers and vendors. For example, many universities and institutes (such as UC Berkeley, Vanderbilt, Memphis, Michigan, Notre Dame, Maryland, and General Motors Research and Development Centre) have joined one research project (http://newsinfo.nd.edu/news/17248-nsf-funds-cyber-physical-systems-project/). The European Union (EU) and other countries, such as China and Korea, also realised the importance and significance of CPS research (http://www.artemis.eu/). In addition, the American Government named CPS as a new development strategy [8]. In conclusions, research and applications of CPS have been active in such areas like transportation, smart home, robotic surgery, aviation, defence, critical infrastructure, etc. [1]. CPS also positively affected manufacturing in form of Cyber-Physical Production Systems (CPPS) in process automation and control [10].

The structure of CPS was outlined in [11], and the IoT, as the Internet layer, networks the "cyber-physical" things for information transfer. IoT can be seen as a bottom-up vision, an enabling technology, which can be used to create a special class of CPS, i.e. systems including the Internet. However, CPS does not necessarily include the Internet. Some visions of the IoT go beyond basic communication, and consider the ability to link "cloud" representations of the real things with additional information such as location, status, and business related data. Therefore, CPS forms the first level and IoT forms the second level of vertical digital integration.

The progress of many research and applications of CPS and IoT is significant, and this chapter systematically illustrates the latest advancements of CPS and IoT, such as in technologies and industrial applications. The remainder of this chapter is therefore organised as follows. The key enabling technologies of CPS and IoT are presented in Sect. 2.2, followed by their key features and characteristics of CPS and IoT in the literature. Advancements of CPS and IoT are provided in Sect. 2.3. Section 2.4 introduces applications of CPS and IoT, before concluding the chapter in Sect. 2.5.

2.2 Key Enabling Technologies in CPS and IoT

Along the progress of CPS and IoT research and applications, Wireless Sensor Network (WSN), Cloud technologies, Big Data, and other enabling technologies play an important role to support CPS and IoT. For example, several initiatives cater for the CPS development, such as Advanced Manufacturing Partnership 2.0 [12] and Industrial Internet [13] in USA, Industry 4.0 [14] in Germany, Factories of Future [15] in EU, and even the less-known Japanese "Monozukuri" that stands for Coopetition. Other initiatives on this front include Wise-ShopFloor for web-based sensor-driven e-shop floor [16] and Cyber-Physical European Roadmap and Strategy (CyPhERS) [17]. In addition, IoT, as new emerging technology, is expected to provide promising strategies and solutions to build intelligent and powerful manufacturing systems and industrial applications by using the growing ubiquity of RFID, and wireless sensor devices [18]. According to the International Telecommunication Union (ITU), the key technologies of IoT contain the RFID technology, Electronic Product Code technology, and ZigBee technology. In what follows, a brief account of these technologies, including WSN, cloud technologies, Big Data, RFID technology and Industry 4.0, is provided.

2.2.1 Wireless Sensor Network

Wireless communication and networking is one of the fast-growing research areas. Significant progress has been made in the fields of WSN [19]. WSN is designed particularly for delivering sensor-related data. It consists of a number of sensor nodes working together to monitor a region to obtain data about the environment. The sensor nodes include MEMS components such as sensors, RF components, and actuators, and CMOS building blocks such as interface pads, data fusion circuitry, specialised and general-purpose signal processing engines, and microcontrollers [20]. These sensors are equipped with wireless interfaces with which they can communicate with one another to form a network. Data gathering is the foundation of data processing and transmission. These sensor nodes can sense, measure, and gather information from the environment and, based on some local decision process, they can transmit the sensed data to the user through a communication protocol. A radio is implemented for wireless communication to transfer the data to a base station (e.g. a laptop, a personal handheld device, or an access point to a fixed infrastructure) [21]. Constraints on resources and design for WSN restrict wide application and development with the demands on volume of data collection and complexity of systems. As a result, by integrating WSNs from different domains, CPS represents one of the major driving forces that go beyond the cyber world towards the physical world [7].

2.2.2 Could Technologies

Due to the explosive growth of data volume and real-time service concept, more rapid methods to deal with these data is required. Cloud computing is used to address the problem of calculating speed and volume. Cloud computing refers to ‘a large-scale distributed computing paradigm that is driven by economies of scale, in which a pool of abstracted, virtualised, dynamically scalable, managed computing power, storage, platforms, and services are delivered on demand to external customers over the Internet [22]. Cloud computing is considered as a new business paradigm describing supplement, consumption and delivery model for IT services by utility computing based on the Internet [23]. Infrastructure as a Service (IaaS), Platform as a Service (PaaS), and Software as a Service (SaaS) are the basic service models of cloud computing, and they indicate hardware resources, cloud platforms including operating systems, programme execution environments and databases, enabling application developers to develop, test, deploy and run their applications [24]. Cloud computing has changed the way of thinking of both IT service providers and their customers. It offers business and application models that deliver infrastructure, platform, software and applications in forms of services [25]. Figure 2.1 illustrates different levels of services of cloud applications compared

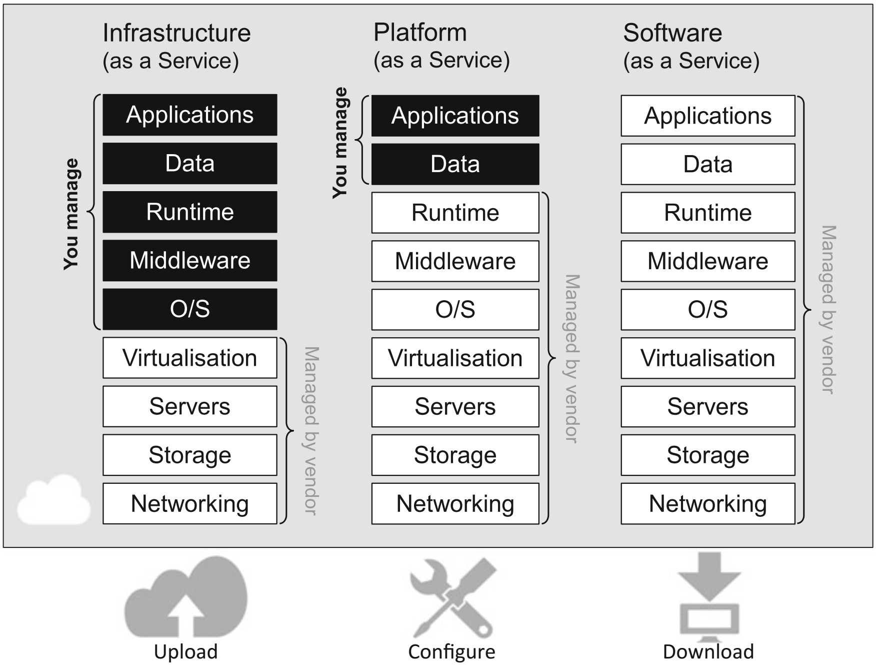

Fig. 2.1 Different service levels of cloud services

against standalone ones. Inspired by the success of cloud computing, the cloud technology has recently been extended to the manufacturing contexts, leading to the innovation of various cloud manufacturing systems. Cloud manufacturing implies an integrated cyber-physical system that can provide on-demand manufacturing services, digitally and physically, at the best utilisation of manufacturing resources [26, 27]. It aims at offering a shared pool of resources, e.g. manufacturing software, manufacturing facilities, and manufacturing capabilities. However, cloud manufacturing is more than simply deploying manufacturing software applications in the cyber cloud. Besides data storage and virtual machines, the physical resources integrated in the manufacturing cloud must be able to offer adaptive, secure and on-demand manufacturing services, often over the IoT, including work-cells, machine tools, robots, etc.

2.2.3 *Big Data*

Big data refers to the analytics based on large data collections. Advancements in computing and memory performance, together with networking have made big data analytics possible to gather and analyse unprecedented amounts of data. Big data has strong interdependency with cloud computing. The lack of cloud computing may result in huge and intensive data becoming useless. In other words, cloud computing provides an effective approach to processing insignificant big data and converting them to meaningful data, which can be efficiently used by end users. With the rapid development of information technologies and industrialisation, the demand for the value-added data services from enterprises and users is dramatically increasing. This also requires patterns of manufacturing and services to transform towards ones based on industrial big data. In addition, the quantity of manufacturing resources such as machines, devices, and materials, etc., have several times as many as than before, and the large scale of data are generated from these manufacturing resources. Industrial sensors, radio frequency identification systems, barcodes, industrial automation control systems, enterprise resource planning, computer aided design, and other technologies are increasingly rich in industrial data volume. These data are huge and heterogeneous, which is difficult to process. Therefore, methods in cleaning data and adding value of data are developed to extract and integrate these data. Besides, professional algorithms are used to analyse these data and find useful information. Therefore, applications of big data in many fields, especially in manufacturing systems, can provide a new paradigm for achieving data-based services and manufacturing pattern transformation. Another important thing in this process is data exchange, including data/information interaction between huge manufacturing resources. The key characteristics of WSN in terms of reliability, flexibility, usability, and security guarantee the stable, high-efficient, and secure data transmissions. CPS and IoT enable further enormous amounts of data related to physical systems to be made available for analysis. Big data is relevant to non-technical systems and IT systems, but becomes even more interesting when applied in the context of CPS due to the implications of physicality in terms of capabilities, technical risks and costs.

2.2.4 Industry 4.0

The term Industry 4.0 was manifested for the first time at the Hannover Fair with the presentation of the "Industry 4.0" initiative [28]. Industry 4.0 is a large German initiative [14] that emphasises the extension of traditional manufacturing systems to full integration of physical, embedded and IT systems including the Internet. It highlights three features for implementation: (1) horizontal integration through value networks, (2) end-to-end digital integration of engineering across the entire value chain, and (3) vertical integration and networked manufacturing systems. The implementation recommendations call for actions in eight key areas including standardisation and reference architecture; managing complex systems; safety and security; work organisation; professional training; regulations, and resource efficiency. Germany's implementation of Industry 4.0 has received great attention throughout the world from researchers and government, and therefore many countries, institutes, and enterprises undertake this research and aim at improving their manufacturing chains. Especially in the process of Industry 4.0, due to the tight integration of micro controller and physical devices, machines and tools are becoming more automated and self-sufficient, increasingly replacing manual labour. Industry 4.0 is a representative of the emergency of the fourth Industrial Revolution through the use of CPS and IoT, followed by *digitisation* through the use of electronics and IT. The goal of the Industry 4.0 is the emergence of digital factories that are to be characterised by the five key features: smart networking, mobility, flexibility, integration of customers, and new innovative business models [29].

2.2.5 RFID Technology

IoT can be considered as a global network infrastructure composed of numerous connected devices that rely on sensory, communication, networking, and information processing technologies [30]. A foundational technology for IoT is the RFID technology, which allows microchips to transmit identification information to a reader through wireless communication. An RFID system is composed of an RFID device (tag), a tag reader with an antenna and transceiver, and a host system or connection to an enterprise system [31]. Radio frequency tags in the RFID system are used to store information. RFID tags and readers communicate by non-contact sensors, radio waves or microwaves. The key technologies of RFID include high-adaptive wireless communication technology, high confidentiality; low power consumption, high reliability of RFID devices; small volume, high-efficiency antenna technology; low-cost chip and reader. The most prominent advantage of RFID technology is: non-contact reading and writing, distance from a few centimetres to dozens of metres, to recognise high-speed moving objects, strong security, and can identify multiple targets simultaneously. Compared with the concept, component parts of RFID technology, the industrial applications of RFID technology attract more interests, for example, sensing and capturing information of objects, and identification. Taking an RFID-enabled real-time information sensing and capturing system as an example, auto-ID techniques such as RFID tags will be employed to manufacturing resources such as machines, robots, and raw materials, to make the smart manufacturing objects with the capability of identifying the real-time status of the manufacturing things such as operators, materials, locations, WIP items, etc. When a manufacturing thing comes to a sensing area, this event can be sensed by the registered sensor. Through the communication protocol, the sensor can capture and send the data of the coming manufacturing things to the upper processing unit, which is responsible for processing the primitive information to form the value-added information and data storage.

2.3 Key Features and Characteristics of CPS and IoT

In this section, the key features and characteristics of CPS and IoT are presented in order to clarify the related advances. It first points out the key characteristics of CPS, and then discusses some features that have been made. Representatives of the industries reported that CPS are indeed not new technologies, but widely existing and manifested by existing industrial manufacturing systems. Lee et al. [32] pointed out that 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 workspace; and (2) intelligent data management, analytics and computational capability that constructs the cyber space. The case can be made to identify and embody CPS, due to the increasing digitalisation and penetration of embedded systems. The increasing connectivity and capabilities of computational systems promote the emergence of new systems with the typical characteristics of CPS, and these characteristics can be concluded as follows: (1) the deployment of CPS in mass-products applications, such as smart-phone enabled services; (2) the chances for and emergence of new cross-domain applications, for example, the intelligent transportation systems; (3) the increasing openness, adaptability, and autonomy.

Wu et al. [33] identified some unique features of CPS applications as follows:

1. Cross-domain sensor sources and data flows: Multiple types of sensors will be adopted at the same time in intelligent CPS applications. Moreover, these cross-domain sensing data will be exchanged over heterogeneous networks.
2. Embedded and mobile sensing capacity: High-degree mobility of sensors based on the mobile devices makes sensors have the capacity of the mobile sensing coverage over time.
3. User contribution and cooperation through give-and-take-like models: Participatory sensing would be common in CPS.
4. Elastic loads requiring cloud-supported storage and computing capability: With the maturity of cloud computing, the pay-as-you-go concept is likely to be adopted in CPS to serve storage, computing, and communication needs.
5. Accumulated intelligence and knowledge via learning and data mining technologies: Under high dynamics and uncertainty of data in CPS, learning and data mining technologies can be used to retrieve useful knowledge. Then, the feedback from users and actuators may help us to accumulate, or even discover unknown knowledge.
6. Rich interactions among many objects and things through the Internet (such as IoT): A lot of sensor–sensor, sensor–actuator, actuator–actuator, actuator–user, user–user, user–object, object–object, object–thing, thing–thing, and thing–user interactions may occur in CPS applications. Such rich and complex interactions demand flexible communication channels, like the Internet, to facilitate our applications.

These characteristics and features of CPS led the CyPhERS (Cyber-Physical European Roadmap and Strategy) project [17] to carry out a characterisation of CPS, attempting to capture the evolving scope of CPS, from traditionally closed systems, with single jurisdiction, limited adaptability and autonomy. Defining such characteristics would be helpful beyond definitions, because definitions of CPS tend to be very general; instead the characterisation helps to identify various types of CPS. The following aspects of CPS have been identified [17]:

- *Deeply embedded versus IT dominated*. Resource-limited and dedicated computer systems represent the traditional embedded systems, which tightly integrates with the physical processes. The increasing connectivity and capabilities of computing systems enable "embedded" versus IT systems for the intersection. This means that the two types of systems are becoming connected and interacted.
- *Single-domain versus cross-domain*. A traditional embedded system generally is represented by a single domain application system. New cost-efficient communication creates the potential for the demands and applications of new services that cut across existing domains, or for building new CPS domains. The smart home and its connection to the electrical grid represent an example of this trend.
- *Open versus closed*. A traditional embedded system represents a system that is not connected to other computing systems. The difficulties of diagnosing, maintaining and upgrading widely deployed embedded systems provide strong driver towards more open systems. Another driver is provided by the ability to provide new collaborative services.
- *Automation levels and types*. Systems with high autonomy can have the capacity of operating without human supervision/intervention. Automation in many fields is used to replace or relieve the workers' load, especially in the dirty, dull, and dangerous working situation [34]. Based on the environmental, resources efficiency and safety considerations, autonomy is widely developed and applied to all kinds of domains (such as intelligent manufacturing systems, and robot-enabled assembly systems).
- *Governance, indicating the entities responsible for dependable and efficient system operation*. The division of responsibility will associate with the system of system nature.
- *Distributed versus centralised control*. Most CPS already constitute distributed computer systems (or are likely to become so) because of the increasing connectivity. This makes control become more or less decentralised. Control in this context refers to the decision making within the distributed systems.
- *Single jurisdiction versus cross-jurisdiction*. This aspect refers to applicable standards and legislation. Generally, the typical challenge faced by many existing CPS is that jurisdiction is more complicated with more open and cross-domain CPS.

- *Adaptability under uncertain conditions*. The context of the typical CPS may be always varying, such as the environmental conditions, system load, and failures. Adaptable CPS has the capacity of dealing with such varying contexts within given bounds, and potentially contributes to reducing maintenance costs and increasing availability.
- *Human in/outside the loop*. Traditional CPS come in two types; those that are more or less fully autonomous (i.e. act independently of humans, but may be triggered by human inputs), and those with a much closer interaction with humans, including shared control.
- *Degree of integration*. Various types of integration are built based on the effective connectivity. A CPS will have a certain degree of horizontal and vertical integration in a certain context and application domain. Horizontal integrationis the integration of services and functions of similar type, and vertical integration refers to integration across system hierarchies.

CPS may pose a different mix of the key features and depend on their utilisation domain. CPS consider the computational decisional components that use the shared knowledge and information from physical processes to provide intelligence, responsiveness, and adaptation. In conclusion, the differentiating factor among all areas, is not the distinct characteristics but which of them they employ (depending on the scenario) and at which degree [35]. Similarly, IoT focuses mostly on the interaction and integration part while cooperation is optional. According to the definition and applications of IoT, characteristics of IoT are different because of specific-domain applications with typical unique features. As discussed in the previous section, IoT can provide technical support and new opportunities for innovative applications in many fields. Some applications strictly belong to a specific domain and exhibit characteristics peculiar of that domain. Conversely, others applications exhibit characteristics cross-cutting multiple domains. As a result, it is unsuitable or hard to identify characteristics of IoT, which is common for applications in all the fields. Under the context of this chapter, the key IoT features in manufacturing systems are introduced as follows, in contrast to the current manufacturing systems [36].

- Introduce an easy-to-use and easy-to-deploy architecture and solution for implementing smart manufacturing in the whole manufacturing systems using the IoT.
- Design the smart framework and models for improving the intelligence of the bottom-level manufacturing resources such as smart stations and smart vehicles because they are the key to the intelligent manufacturing system.
- Develop a new decision strategy and method for real-time information based production scheduling and internal logistics optimisation, which can be directly applied to the manufacturing system, for example, shop floor, for improving the efficiency.
- Present a critical event-based real-time key production performances analysis model, so as to actively identify real-time production exceptions.

These key IoT features provide the technical support and basis for addressing the "4Cs" (Connection, Communication, Computing, and Control) of resources and devices for the following different applications in manufacturing, and achieving the connection of objects.

2.4 Applications of CPS and IoT

CPS has achieved varying applications in different sectors, and they include highly reliable medical devices and systems, traffic control and safety systems, advanced automotive systems, and systems for process control, environmental control, energy conservation, instrumentation, critical infrastructure control, distributed robotics, smart structures, manufacturing, and defence [1, 6, 37]. Widely recognised and accepted attributes of a CPS, such as timeliness, distributed, reliability, fault-tolerance, security, scalability and autonomous, are also identified. In addition, the concept and technologies of IoT can be extended into many fields and various application backgrounds to achieve connection, communication, and interaction of the physical things in a constructed Internet-of-Manufacturing-Things environment, such as manufacturing systems, logistics, intelligent transportation, and supply chain management, etc. Moreover, in a constructed sensing environment, real-time data of things, such as manufacturing resources, can be sensed and captured by the registered sensors. Based on a carefully chosen communication protocol, these accurate, timely, consistent, and value-added data can be transmitted to the upper data processing units, and further shared among manufacturing managers and suppliers. Real-time monitoring, tracking, and tracing of manufacturing resources and devices through the entire manufacturing chain can be achieved. In this chapter, by taking the main research topics into considerations, the main focus is given to applications of CPS and IoT in manufacturing systems and services. Consequently, typical and representative cases are introduced in the following sections, including service oriented architecture, could manufacturing, an IoT-enabled manufacturing system, and CPS in the cloud environment. These examples of manufacturing systems and services can reflect many of the CPS and IoT characteristics and features described in Sect. 2.4.

2.4.1 Service Oriented Architecture

Service-oriented architecture (SOA) is one of the key technologies for information communication [38], and plays an important role in connection between the cyber world and physical world. The advantages of SOA are essential for manufacturing systems, and they are comprehensive, distributed, transparent, and secure [39]. These advantages provide technical and strategic support for enterprises to manage their workflows, optimise their manufacturing chains, select the most optimal suppliers, share information, monitor the performance of devices, and guarantee the information security. They cater for the requirements and demands of a growing number of industrial systems, including integration flexibility and the ability for processes to be composed. CPS has the capability of the integration of the computational and physical worlds. Under the constructed infrastructure service platform, sensors registered/installed in the workspaces of factories sense and capture the physical information of manufacturing resources around them. After capturing these data, instead of directly entering optimisation stage, adaptive control mechanisms are entailed to achieve the added value and management of real-time information [40, 41]. These data are transformed to the upper control systems integrating computation, sensors and actuators in devices, which will then give instructs to actuators for execution. Finally, manufacturing systems supply the support of M2M (including man-to-man, man-to-machine, and machine-to-machine) communication, break the limitation of source constraints, and achieve resource sharing and distributed computing.

In this section, a representative application of SOA is introduced and it is a Ford Motor Company application to the Valencia assembly plant (Ford Transit models) [1], which is one of the first service-oriented architectures effectively deployed in industry and is still used at present. Developed by a system integrator (IntRoSys SA), this approach left all current product lifecycles (PLCs) as they were. According to the architecture shown in Fig. 2.2, agent technology (having Product, Knowledge Manager, Machine agents) is the key enabling technology encapsulated as “wrappers” to the PLCs.

As shown in Fig. 2.2, a Product Agent (PA), a Knowledge Manager Agent (KMA), and a Machine Agent (MA) form the basis of agent enabling technology for the service-oriented architecture of an IntRoSys Multi-Agent System. The PA is responsible for formulating and dispatching the workflow, and the KMA is to perform a check of the physical feasibility of the proposed workflows. The MA translates the workflows into specific machine instructions. The procedure of these agents can be described as follows. The PA receives the order and identifies the Atomic Skills required. The following step is a match of such required Atomic Skills with a database of workflows already executed in the past. If the order can be executed with an existing workflow, then such a workflow is dispatched to the MA, else the PA elaborates a new workflow that is sent for a feasibility check to the

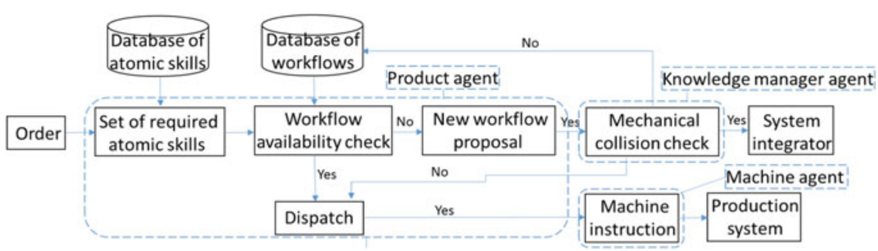

Fig. 2.2 Service-oriented architecture of IntRoSys multi-agent system

KMA. If the KMA does not detect any problems, the examined workflow is sent back to the PA that dispatches it to the MA. The newly found feasible workflow is also included in the database of existing workflows. Vice versa, in the case of problems with the proposed workflow, the MA warns the System Integrator for the necessity of a human intervention to sort out the related order. Finally, all the dispatched workflows are processed by the MA that sends the necessary machine instructions to the production system. This service-oriented agent architecture is open in the sense that if a new atomic skill (for example a new process for a new variant, or a safety routine) is required, it can be integrated in the system without modifying the existing code but simply by coding it independently and eventually adding it to the related database.

2.4.2 Could Manufacturing

Cloud manufacturing is emerging as a new manufacturing paradigm as well as an integrated technology, which is promising in transforming today's manufacturing towards service-oriented, highly collaborative and innovative manufacturing in the future. Combining recently emerged technologies, such as IoT, Cloud Computing, Semantic Web, service-oriented technologies, virtualisation, and advanced high-performance computing technologies, with advanced manufacturing models and information technologies [42], Cloud Manufacturing is a new manufacturing paradigm built on resource sharing, supporting and driving the flexible usage of globally distributed, scalable, sustainable, service-oriented manufacturing systems and resources [43]. Cloud manufacturing is also a smart networked manufacturing model that embraces cloud computing, aiming at meeting growing demands for higher product individualisation, broader global cooperation, knowledge-intensive innovation and increased agility in market response. In cloud manufacturing, customers can conveniently obtain on-demand services supporting the entire lifecycle of a product through network access to a shared pool where distributed manufacturing resources are virtualised and under unified management in a configurable and optimised manner [24]. Xu [44] defined could manufacturing as a model for enabling ubiquitous, convenient and on-demand network access to a shared pool of configurable manufacturing resources (e.g. manufacturing software tools, manufacturing equipment, and manufacturing capabilities), which can be rapidly provisioned and released with minimal management effort or service provider interaction. Over the past years, there have been different definitions of cloud manufacturing. In general, cloud manufacturing is a system that can provide manufacturing services digitally and physically to best utilise manufacturing resources [27]. In essence, it must connect to the real manufacturing equipment to form a CPS [37]. Along this direction, an integrated CPS for cloud manufacturing is presented hereafter, aiming for improved remote accessibility and controllability of factory equipment, such as CNC machines and robots, by combining 3D models, sensor data and camera images in real-time. It is realised by significantly reducing network traffic over the Internet, and building cloud-based services of monitoring, process planning, machining and assembly in a decentralised environment.

Cloud-DPP (cloud-based function-block enabled adaptive distributed process planning) is a joint research effort between KTH and Sandvik, Sweden, aiming for cloud-based distributed and adaptive process planning in a shared cyber workspace. Figure 2.3 depicts the architecture of distributed process planning (DPP), real-time process monitoring, dynamic resource scheduling, and remote device control of CPS. Based on the real-time information of machines and their status, DPP handles adaptive decision making of process planning. It is also possible for the Cloud-DPP to generate machining process plans adaptively to changes through well-informed decision making [45]. This is done by linking sensors embedded/attached to each machine to a manufacturing cloud in the cyber workspace, and delivering process plans in function blocks to the machine controller on the physical shop floor for execution. By properly dividing process planning tasks and assigning them to the cloud and function blocks, adaptive process planning and machining become possible. Cloud-DPP elaborates a two-layer distributed adaptive process planning based on function-block technology and cloud concept.

Cloud-DPP service obtains data from the monitoring service (machine tool ID, current status, and available time windows) and the feature list of a new part to be machined. The service uses a three-layer structure comprising supervisory planning (SP), execution control (EC), and operation planning (OP) [46, 47] (Fig. 2.4). At first, after having received input from the higher-level production planning, SP generates a generic process plan through generic setup planning and sequencing.

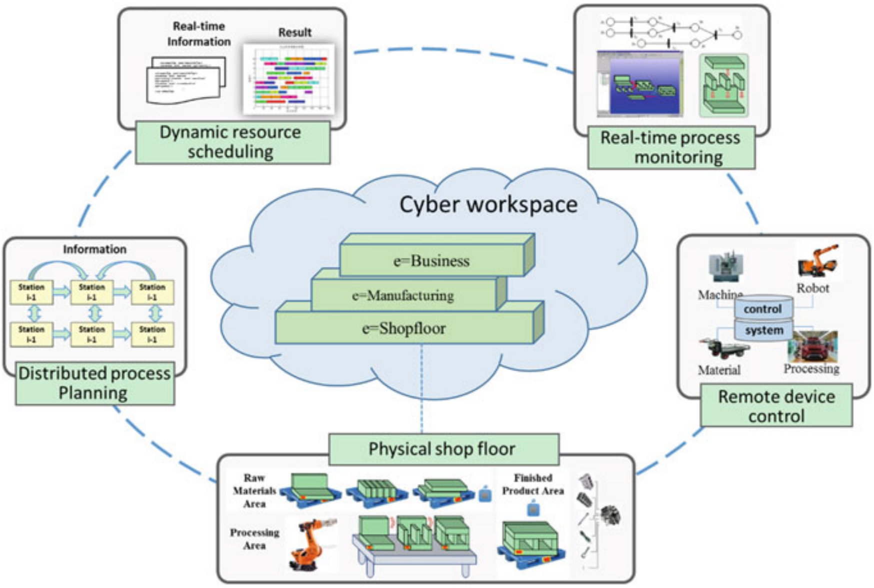

Fig. 2.3 Could-DPP in a cyber-physical system

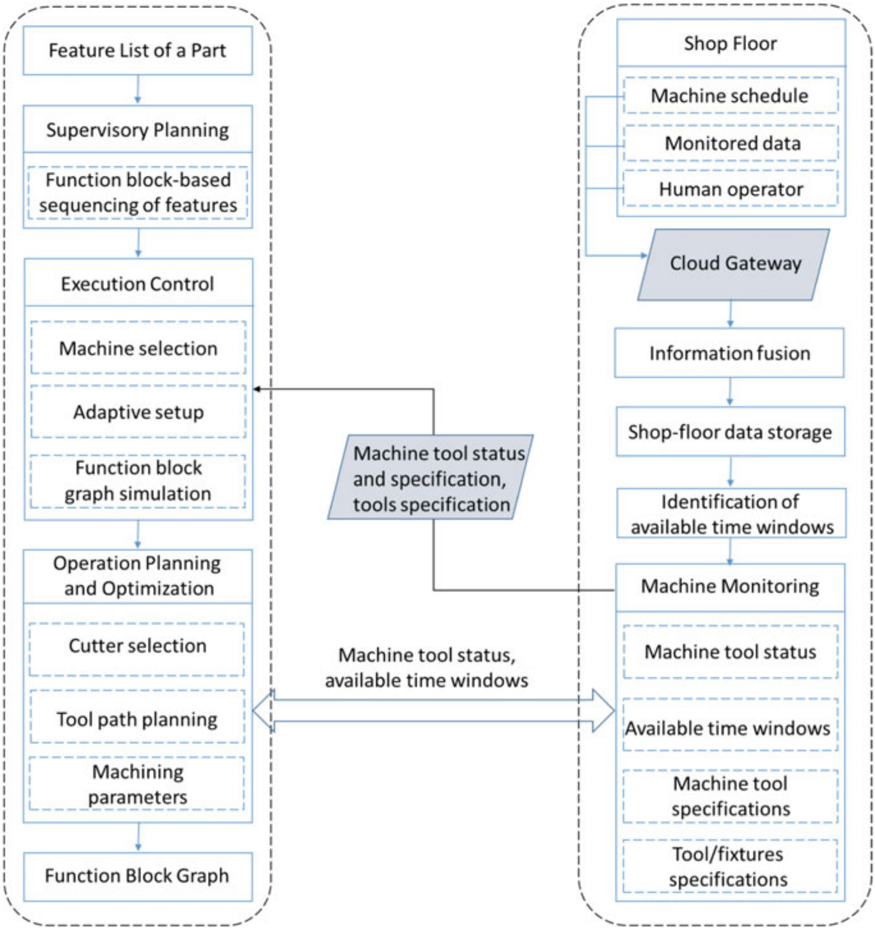

Fig. 2.4 Workflow of Could-DPP

A generic process plan is a nested directed graph in which the nodes are the sequenced setups with machining features grouped in each setup, and the edges represent precedency relations among the nodes. A generic setup is a group of machining features with the same tool access direction that is possible to cut at least on a 3-axis machine. Later, it would be possible to assign any generic setup to any 3-, 4-, or 5-axis machine independently or merge it with other generic setups if the machine can handle them in a single setup. The precedence relations are decided by sequencing algorithms that infer necessary and preferred precedence among the machining features and setups by means of various rules addressing different aspects such as datum references, tolerances, and machinability. For each machining feature in the generic process plan, one machining feature function block instance is created. A generic process plan is completely resource-independent and the function blocks at this stage of their lifecycle are called meta function blocks. Then, the EC performs machine selection, adaptive machine-specific setup planning, and job dispatching. During this phase, in case the machine tool has more than three machining axes, the generated generic setups should be further merged and adapted to the available machine configuration due to higher tool reachability [46]. This will also ensure a higher efficiency of machining process as the number of setup changes decreases. When multiple machines of different characteristics are available, it leads to an optimisation problem in which the best way of distributing tasks among available machines based on defined criteria is targeted.

2.4.3 Cyber-Physical Production Systems

One example of CPS in manufacturing is a cyber-physical production system (CPPS), which uses the combined strength of holons, agents and function blocks [48]. In this context, a CPS is represented by a holarchy of multiple holons. A logical and physical parts that mimic the cyber and physical entities of the CPPS constitute a holon. When implementing this holonic CPPS, agents and function blocks are adopted to realise the two aspects of a holon for information processing and materials processing, respectively. Holons and agents have attracted growing interests in the field of manufacturing control because of the typical challenges from continuous changing manufacturing demands and patterns such as decentralisation, frequently shifting technologies, and various market perturbations. Function blocks as machine-level execution and control standards, are regarded a suitable approach to modelling distributed manufacturing systems and fit well with the concepts of holons and agents [49, 50]. Integration of holons, agents and function blocks can represent and model a CPPS, which is intelligent and adaptive, and can cope with challenges faced by manufacturing systems in the future. In order to understand the holonic CPPS and its potential in manufacturing, in the following we briefly introduce holons, agents and function blocks in terms characteristic.

Agent, as the core of agent technology, is defined as a software entity situated in some environment, that is capable of autonomous action in this environment in order to meet its design objectives. Another definition of agent is as follows: an agent is an autonomous component that represents physical or logical objects in the system, capable of acting in order to achieve its goals, and being able to interact with other agents, when it does not possess knowledge and skills to reach alone its objectives. This means that an agent should have the capacity of interaction without the direct instruction of higher authorities or intervention of humans, but instead in negotiation with other agents if necessary. A network of agents can be used to build a multi-agent system (MAS), which can be best characterised as a software technology having the capacity of modelling and implementing the individual and social behaviour in distributed systems. Six main characteristics of agents are concluded as follows: (1) reactive: agents should be able to sense their surrounding environment and react to the changes that occur; (2) proactive: agents should be capable of achieving their assigned goal; (3) autonomous: agents should have enough knowledge and authority to operate and act on their own without direct instructions or intervention from humans or other agents; (4) cooperative: agents can interact with other agents if necessary to achieve the global objective of the system; (5) adaptive: agents can learn from their previous behaviours and can apply their experiences to future scenarios; and (6) mobile: agents can move through a network [48].

Holonic manufacturing system (HMS) is defined as a group of holons that integrate the whole process of manufacturing activities from order booking through design, production and marketing to realise the agile manufacturing [51]. Where holon is an autonomous and cooperative building block of a manufacturing system for transforming, transporting, storing and/or validating information and physical objects. A holon consists of an information processing part and often a physical processing part, and also be a part of another holon. The characteristics of holon are autonomous, cooperative, open, proactive, reactive, learner, and recursive. Some of them have the similar attributes and capacities with that of agents. We briefly introduce some of them, for example, autonomy indicates the capability of the building block to create and control the execution of its own plans and strategies, and cooperation is defined as a process whereby a set of building blocks develops mutually acceptable plans and executes these plans. In addition, the holarchy denotes a system of holons that can cooperate to achieve a goal or objective, and defines the basic rules for the cooperation of the holons and thereby limits their autonomy. A holon can dynamically belong to multiple holarchies.

Function blocks can be applied in distributed environments and can be dispatched to machine tool controllers. In fact, each function block is a control software unit that is embedded with necessary information and algorithms that are required for performing a task at the controller level. An internal finite state machine would be responsible for controlling the different states and transition of sub-tasks within the function block. Function blocks have the capacity of producing different outputs using an identical input through changing the internal states of the function block to automatically expand their application. Function blocks can be classified into two main categories, namely basic function blocks and composite function blocks. The basic function blocks use their internal data and algorithms to perform a task, and a composite function block only relies on its containing basic function blocks' behaviours, but is not embedded with internal information. The event input of the function block triggers the execution of tasks. An execution control chart is responsible for denoting the execution control states, transitions and actions of that function block instance. Finally, when the task is finished, the function block's event output will send triggering signal to the next function block.

To make a holonic CPPS clear, the overall architecture of a robot holon that can be implemented by the multi-agent technology and function blocks is presented shown in Fig. 2.5. It is composed of a layered structure from the bottom to the top, including the physical part layer, the control system layer, and the planning, scheduling and execution control layer. The physical part layer contains the actual physical equipment on the shop floor, such as sensors, robots, and actuators, and is

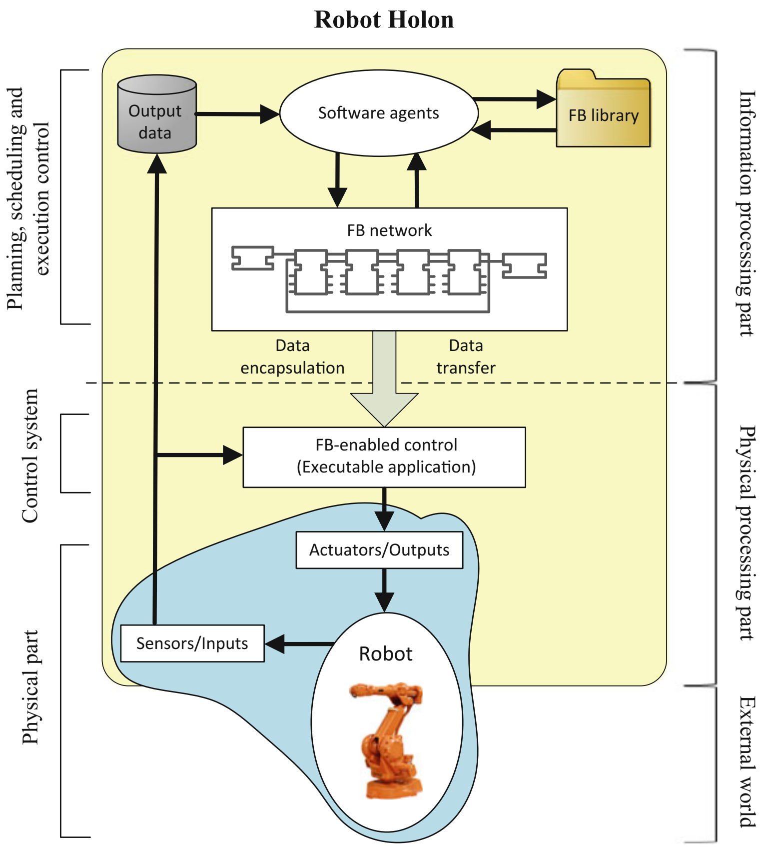

Fig. 2.5 MAS and function blocks embedded in a holon

connected to the control system layer. In the control system layer, function block-enabled control system completes the work of translating tasks to native machine control codes that are transmitted into the physical part layer, then, machines in the physical part layer execute operation instructs. The planning, scheduling and execution control layer is responsible for planning and scheduling, decision making, developing control instructions and transferring them to the control layer where these instructions can be executed as runtime codes. The software agents would be responsible for high-level decision-making and coordination, and function blocks at the lower controller level would be responsible for execution of processes on the machine and quick fault recovery in case of disturbances on the shop floor. However, data will be processed by the software agents in complex cases because of the lack of the capacity of fault recovery for function blocks. The decision-making agent, and communication/collaboration agent are integrated into the software agents at the information processing part of the holon, where the decision-making agent achieves communication and interaction with other decision-making agents embedded in other individual holons within a holarchy and humans through the communication agent. As mentioned before, a CPS considers two different layers of "cyber" and "physical". The layered structure of the robot holon shown in Fig. 2.5 matches the structure of CPS and allows for distributed control. The information processing and physical processing of a holon can be connected through a wide area network (WAN) that can be geographically distributed. These separated parts of the holons can replace the traditional constitutive elements of the CPS; for example, the logical parts of the holons as decision-making units in the cyber part of the CPS, and the physical parts of the holons as execution units in the physical part of the CPS. Agents in the logical part of a holon for information processing can sense their surrounding environment and the conditions of their representative physical part on the shop floor. Due to limited awareness of a single agent, they need to build the intercommunication with other agents to obtain knowledge of the surrounding environment. As a result, agents of different holons can create cooperative groups (within a holarchy) for improving the quality of decision making. Humans as another element of a CPS can monitor the status and actions of physical entities through visual interfaces and can also enter the decision-making process when needed via communication agents.

Finally, we introduce a hypothetic manufacturing CPS that consists of two conveyors, two robots, and one machine, and produces a single type of product, and this can show the future potential of CPS in manufacturing. The raw material is fed through the first conveyor and is then transferred to the machine by a robot. Once the machining process is finished, the second robot would unload the finished part from the machine and place it on the second conveyor.

For the sake of modelling manufacturing CPS, the following assumptions are made: there is no buffer limit for the products after the second conveyor and before the first conveyor, and different robots are used for loading and unloading. One holarchy of eight defined holons is used to represent the hypothetic CPS: (1) a raw material holon, (2) a product holon, (3) an order holon, (4) conveyor holon-1, (5) conveyor holon-2, (6) robot holon-1, (7) robot holon-2, and (8) a machine holon. By applying the design concepts [48], CPS can be modelled. Different sets of connections among these holons represent the possible inter-holon communications for dynamic planning, scheduling and execution that can be implemented by agents and function blocks. In the case of tool breakage occurring while machine holon is in the middle of machining process. In order to stopping the spread of damage, the hard real-time control system will halt the process in real time and retract the tool away from the part. Considering the current conditions, function blocks will then adjust the process plan using the remaining available tools. The information of the new condition (i.e. tool breakage) is also sent to the information processing part of the machine holon. The information processing part will then communicate with the conveyor and robot holons, and updates them about the new condition so that they can make appropriate decisions such as delaying their processes or slowing down. To find an alternative process plan for the machine holon, its current machining state, geometry, etc., will be updated through building the communication between the machine holon and in-process part. For example, a second machine (machine holon-2) exists on the shopfloor in parallel to machine 1, and is currently off. It is assumed that machine holon-1 has found the best alternative process plan with its remaining tool sets, however, the cycle time using this plan would be more than the previous approach. As a result, machine holon-1 communicates with order holon and finds out that current production rate will not satisfy the demand in the remaining timeframe. Furthermore, the replacement tool is not currently available in the inventory and would not become available in time. Machine holon-1 will communicate with machine holon-2, to see if it can help with the production of parts in order to satisfy the demand in time. Machine holon-2 will then communicate with the part holon, raw material holon and order holon to get information on the part and its specifications, and to see if it can fabricate the part. The process plan is then generated, encapsulated in function blocks and dispatched to the machine 2 controller for execution. The presented scenario is a simple case that may frequently occur on the shop floor. A CPS modelled through holons, function blocks and multi-agent systems are capable of automatically processing these data and adjusting the system to the new conditions. Humans can also monitor and control the processes through designed user interfaces.

Different sets of connections among these holons (shown as dashed arrows in Fig. 2.6) indicate the possible inter-holon communications for dynamic planning, scheduling and execution that can be implemented by agents and function blocks.

2.4.4 IoT-Enabled Manufacturing System

In manufacturing, IoT technology is rapidly developing under the support of RFID, sensors, smart technology, and nanotechnology, and it is expected to promote interconnection of anything. Furthermore, IoT is helpful to construct a platform for sharing and interconnecting all kinds of manufacturing resources. Applying the generalised IoT into manufacturing industry can be used to address the connection, communication, computing, and control of manufacturing resources. Coupled with the rapid development of embedded systems and technologies, it provides enabling technologies for realising intelligent embedding of physical terminal equipment and the interconnection of M2M in manufacturing.

This section presents an IoT-enabled manufacturing system (IoTMS), and the focus is placed on sensing and capturing real-time information of manufacturing resources, real-time system monitoring, and the optimisation of manufacturing systems. IoTMS denotes a multisource real-time data-driven manufacturing system, covering monitoring, decision making and management from the production orders assigned to the required work-in-progress or finished products [36]. Hardware such as RFID devices, sensors, manufacturing resources, etc., are used to build an IoT-enabled sensing environment through the configuration of RFID devices, and sensors, and further sensing and capturing real-time information of manufacturing resources. Software integrates algorithms, modelling methods, and communication technologies, and therefore, has the capacity of analysing, computing, reasoning,

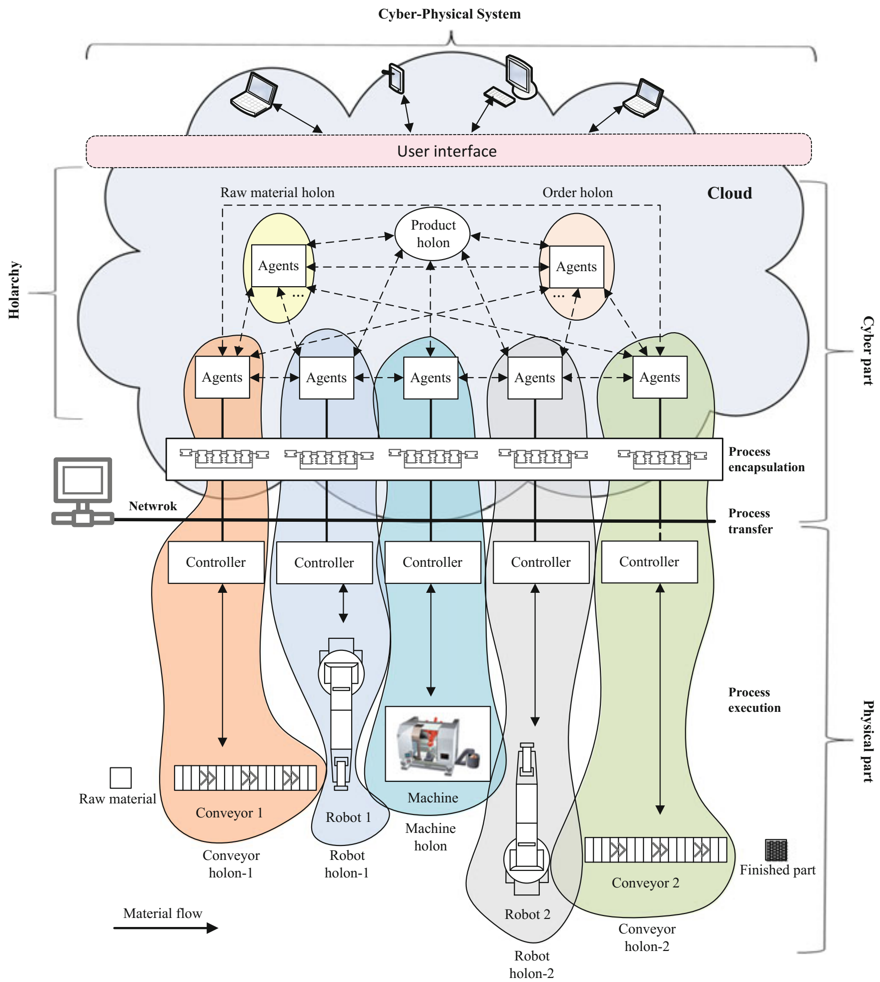

Fig. 2.6 A hypothetic CPPS modelled using holons, agents and function blocks

controlling, and decision making. As one of the key technologies of the IoTMS, a real-time and multisource manufacturing information sensing system is responsible for sensing and capturing real-time information of manufacturing resources in the IoTMS, and this is the foundation of IoTMS. The architecture of real-time and multisource manufacturing information sensing system is designed as Fig. 2.7. This architecture is composed of four layers from the bottom to the top, namely the configuration of multiple sensors, sensors management, multisource manufacturing information processing and sharing, and management systems.

The configuration of multiple sensors, as shown in the bottom of Fig. 2.7, is to construct an IoT-enabled smart sensing environment for the physical manufacturing

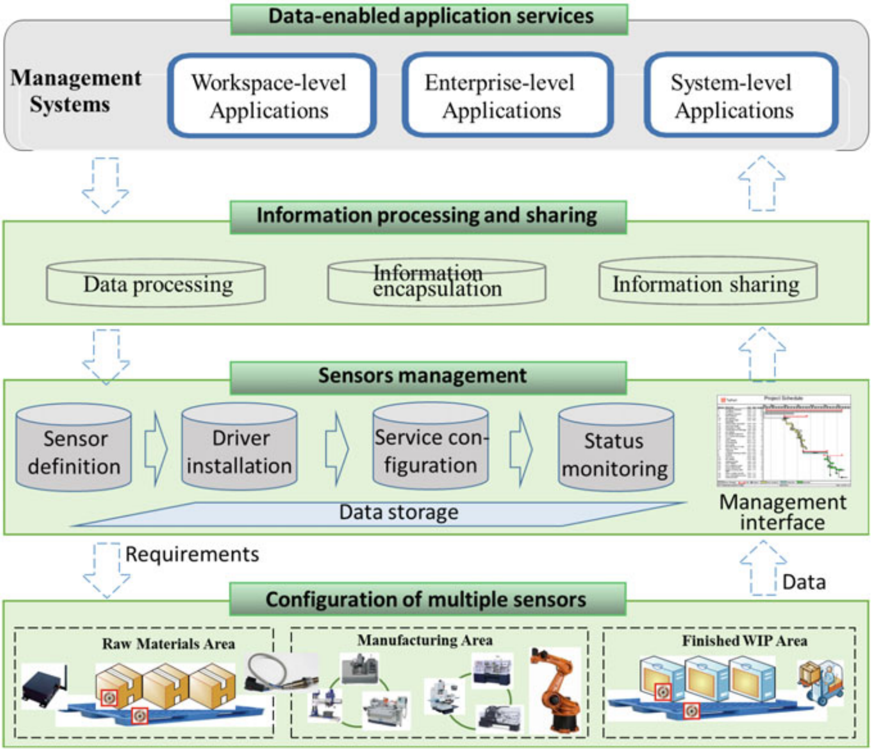

Fig. 2.7 A real-time multisource manufacturing information sensing system [36]

resources. There are many manufacturing resources in the shop floor/workspace, such as machines, robots, raw materials, devices, and work-in-process, the status information of these manufacturing resources are constantly changing along the changes of manufacturing processes. As a result, huge amount of data related to these manufacturing resources are created in real-time. However, these data are heterogeneous because of the different attributes of manufacturing resources. To select fitting type of sensors for the configuration of intelligent sensing environment, the manufacturing information that is required to be collected is analysed and determined, and then, the needed sensors can be selected and configured in this module. This is based on the consideration of cost in the construction of intelligent sensing environment. For example, users in a manufacturing system show more interest in data related to machines, process quality, production objects, worker, and manufacturing environment. The information of different sensor, e.g. type, hardware interface, cost, target manufacturing resource, function, and reliability, would be analysed, and the fitting sensors are selected to build a smart sensing environment in the physical layer of manufacturing systems.

The sensors management module is responsible for managing sensors and monitoring the working status of the sensors. First, the sensors deployed in the manufacturing systems are registered into the platform of this module. The parameter information of the sensors is input in the registering system, including type of the sensor, its frequency (UHF or HF), interface (USB or COM), inter-communication protocol, data type, record means, reading method, etc. This step is to ensure the data collection in real time after sensors installation. Then, right sensors are installed in the right locations. In addition, the sensor drivers are installed to ensure the sensors operate reliably. However, due to the fact that the heterogeneous sensors have various embedded software, communication protocol, and access right, and so forth, the standard interface and drive library are used to address the heterogeneity of sensors. For example, the standard interfaces are used to drive the sensor, and the system downloads the third-party driver from the Internet according to sensor type, brand, and version, and then install it in the system and update the driver library with the latest edition. The service-oriented architecture is developed to integrate the sensors with different working mode into a uniform pattern under the same platform. In this architecture, the heterogeneous sensors can be published, searched, and invoked through the Internet. To invoke and manage all the sensors registered in the manufacturing system, each sensor will be designed and assigned a single service address and service ID, and all of the service addresses and ID are encapsulated into the standard web service. As a result, the heterogeneous sensors can be managed effectively, and the multisource and heterogeneous manufacturing data can be captured easily. Finally, the operating status of sensors is monitored by this module in real time, Further, the exceptions of sensors can also be sensed and handled to guarantee a stable condition of the sensor network.

The multisource manufacturing information processing and sharing module consists of information processing, information encapsulation, and information sharing. Huge amounts of real-time manufacturing data sensed and captured by the sensors are chaotic, and insignificant. As a result, the information processing is necessary and important to generate value-added information. On one hand, the value-added sensor data are the real interest of the managers/users; on the other hand, the processing of information added value can filter out the primitive and meaningless data and reduce the size of data. Besides, the data storage space can be saved. The information sensed by sensors originally is defined as the primitive information, and the value-added information is defined as the key information. After achieving the added value of information, information encapsulation is used to encapsulate value-added manufacturing data into a standard information template. After the encapsulation, the value-added manufacturing information can be stored under a standard form, easily accessible by different managers. Manufacturing information sharing module is responsible for sharing the valuable information among managers and users. Information sharing relies on the information communication technologies. Therefore, in the designed “Push model” and “Get model” communication methods, users are required to register their information first. Then the real-time and multisource manufacturing data can be published, and users can subscribe, search, and invoke the data they need. For example, in the Push model, the users submit their basic information, such as the user name, web address, and requirements, etc. Once submitted information is captured in the system, value-added real-time information meeting the needs of the users will be sent to the web address through wireless communication such as Wi-Fi.

Enterprise information system is responsible for providing information application services, which consist of application in the workshops, and enterprises, as well as among the big enterprise systems. The first is to provide the data service for the access, identification, and control of the physical manufacturing execution process from materials and semifinished products to the final products. The data identified and acquired from the IoT-enabled workshop manufacturing layer are materials, product, and production related the workshop information system. The second is to provide data service of integrating the production-related information, the product-related information, and other business management information, as well as the integration of the IoT-based workshop and other enterprise information subsystems. The third is to share the manufacturing data, manufacturing resources, and manufacturing services with other enterprise systems. This can achieve the optimal collaboration of manufacturing resources, and data sharing services, and dynamic optimisation of enterprise information.

2.4.5 CPS in Cloud Environment

Over the last decades, Industry 4.0, initiated in Germany, is to promote the effective use of the latest information and communications technologies in real industrial applications towards smart factories of the future [52]. CPS, as the core technologies of Industry 4.0, is usually connected through the Internet, and recently applied the concept of the cloud to form cyber manufacturing [4]. Using the power of cloud computing and facilitated by the real-time connectivity to physical machines and robots (IoT), cyber manufacturing is able to realise true-sense CPS with various functions in one closed loop. In essence, cloud-based cyber manufacturing is an integrated CPS that can provide on-demand manufacturing services digitally and physically to best utilise distributed manufacturing resources and capabilities from anywhere [27]. The architecture of cloud-based cyber manufacturing system, shown in Fig. 2.8, adopts a three-tier view-control-model (VCM) design pattern and a segmented (public vs. private) network structure to address the requirement of efficient and secure data communication between cyber systems and physical systems in the cloud environment.

The Application tier is the application server in the cloud, which handles major security concerns; for example, session control, user registration, sensor data collection and distribution, and physical systems manipulation. This tier connects with the physical factory network, which contains the manufacturing resources and devices of factories, such as machines, and robots. *Signal Collector*, a server-side module, is responsible for collecting sensor data from networked physical machines or robots. After capturing the sensor data, *Signal Publisher* receive these data, and publishes and transmits the sensor data to the registered users, and uses the popular

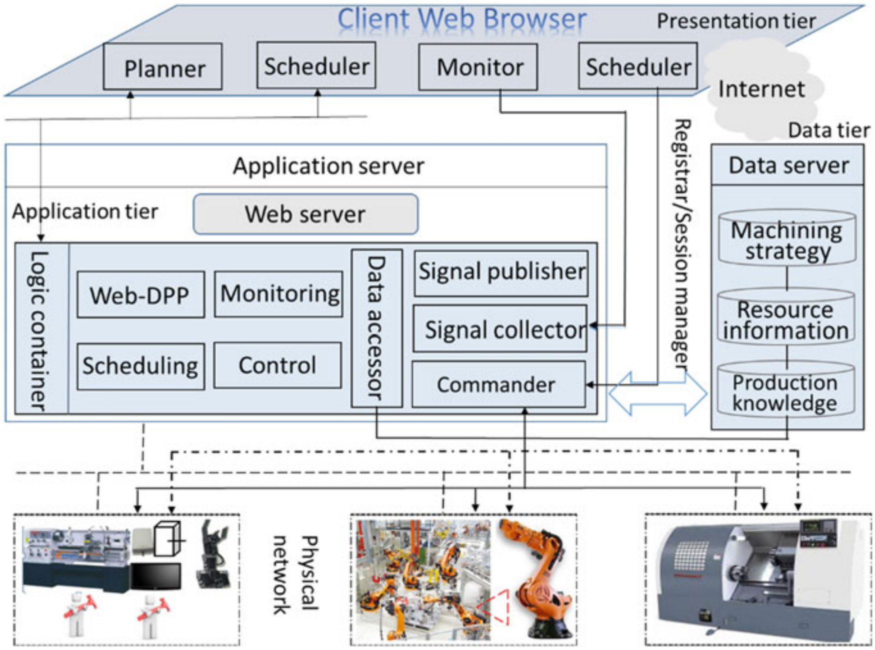

Fig. 2.8 Architecture of a cloud-based cyber manufacturing system

publish-subscribe design pattern to distribute the sensor data at the right time to the right users. A *Session Manager* is designed to search for issues such as user authentication, information synchronisation, session control and data logging. All the initial transactions must pass this module for access rights authorisation. The *Registrar* is designed to maintain a list of subscribers (users) together with the requested sensor data. For the sake of security, the *Commander* that functions like a proxy, through a distributed device network with tight security constraints, is used to control a physical machine or robot [53]. The *Signal Publisher* uses a Pushlet [54] for implementation.

The Presentation tier is essentially a browser-based user interface where planner and scheduler can operate. Users still have the flexibility of monitoring machining and assembly operations from different perspectives, even though, the real-time sensor signals control the behaviours of the 3D models, e.g. selecting different 3D models and viewpoint control and so forth through the *Cyber Viewer*. An authorised user may submit a control command from anywhere to the cloud application server through the *Controller*. The *Commander* at the server-side then takes over the control rights for real machine/robot manipulations. The *Monitor* provides the operator with runtime status of the real equipment. For troubleshooting purpose, a user-side *ChatRoom* (not shown in Fig. 2.8) is designed for synchronised messaging among connected users.

The Data tier is a data server that stores both 3D models and relevant engineering data/knowledge, and machining strategy, resources information, and production knowledge are integrated into this server. *Data Accessor* in the Application tier is designed to provide a standard means for non-sensory data access, and the purpose of this is to separate logical and physical views of data. Moreover, obtaining runtime status of a robot for real-time monitoring is often limited by the available network bandwidth. The best way to reduce network congestion and to ensure quick data transmission in the cyber workspace is to have the data multicast to only the users requiring the data whenever the data is changed. For example, user subscribes to data pertaining to a specific robot, leaving an open connection to receive events (or sensor data updates). When a new event for the robot is posted, it is published only to this user who has subscribed to it. This task is handled by a modified pair of Pushlet and Postlet. A physical system (a robot) can be modelled in the cyber workspace using Java scene graphs for achieving visual monitoring [55]. The same is applied to implement the user interface, specified in the scene graph that enables intuitive navigation in the cyber world. Cloud-based monitoring and remote control for a physical robot can be achieved in the system configuration in cyber-physical environment. TCP (Transmission Control Protocol) is adopted in the design for data communication between the robot controller and the application server, whereas (Hypertext Transfer Protocol: HTTP) streaming is used for data sharing from the server to the remote users. These control and transfer protocol can provide hardware and software protection for robots. Using this design, the CPS allows a remote user to monitor the motions of all joints and to control the robot for remote assembly operations. For the cloud-based remote monitoring and control mentioned above, an operator mainly focuses on what is going on at the robot side, once separated from a robot. This means that motion monitoring must be presented intuitively to guide the operator for remote control. This is then facilitated by condition monitoring in terms of vibration, force, temperature, and so forth, on how well it is doing. While camera-based approach is common and instrumental for motion monitoring, its bandwidth consumption can easily create a bottleneck for cloud-based real-time applications, which is the main concern of this application. To address this problem, a virtual 3D model entirely driven by real sensor data is used for cloud-based monitoring. The testing results of a mini-cell assembly case study reveal that a roundtrip latency of 30 ms is achieved using this approach, which is fast enough to be considered as real-time at the system level. This delay depends more on the network speed than the CPU speed.

2.5 Conclusions

This chapter introduces the latest advancement of Cyber-Physical Systems (CPS) and Internet of Things (IoT) from multiple aspects. Firstly, a brief introduction is presented to better understand CPS and IoT. Wireless sensor network, cloud technologies, big data, Industry 4.0, and RFID technology, as the key enabling technologies related CPS and IoT, are also introduced. Then, key features, and characteristics of CPS and IoT, especially in real applications and projects, are explained. Finally, the typical and representative application examples of CPS and IoT are outlined to highlight the latest advancements.

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http://www.springer.com/978-3-319-67692-0

Cloud-Based Cyber-Physical Systems in Manufacturing
Wang, L.; Wang, X.V.
2018, XVII, 404 p. 193 illus., 163 illus. in color.,
Hardcover
ISBN: 978-3-319-67692-0