A Framework for Integrating Industrial Product-Service Systems and Cyber-Physical Systems

Maokuan Zheng[1], Wenyan Song[2(✉)], and Xinguo Ming[1]

[1] School of Mechanical Engineering,
Shanghai Jiao Tong University, Shanghai, China
zhengmaokuan@163.com, xgming@sjtu.edu.cn
[2] School of Economics and Management, Beihang University, Beijing, China
songwenyan@buaa.edu.cn

Abstract. The transformation to service economy calls for the development of Industrial Product Service Systems (IPS2), which has changed traditional business models greatly. In recent years, there are trends and needs from the industry to further develop IPS2 by integrating advanced information technologies. While the emergence of Cyber-Physical Systems (CPS) provides whole new viewpoints and approaches for IPS2 construction, there are still no public recognized systematic solutions. To solve this problem, the concept of intelligent IPS2 and a framework integrating IPS2 with CPS is proposed in this work. The system decomposition and intellectualization process of intelligent IPS2 are analyzed, trying to figure out the interaction mechanisms between IPS2 and CPS. Then A general architecture of CPS supported intellectualization of IPS2 is developed, which is constructed by five layers. The model for intelligent IPS2 is put forward based on industry investigation, trying to offer possible guidelines and roadmap for those service transforming companies.

Keywords: Industrial Product Service Systems (IPS2) · Intelligent IPS2, Cyber-Physical System (CPS) · Business model · Value co-creation

1 Introduction

As the society developing towards service economy, researches on Industrial Product Service Systems (IPS2) have received great attention from both academia and industries [1]. Advantages of the development of IPS2 are widely discussed. New business models based on service logic have been showing significant power in achieving sustainable economy [2]. IPS2 is integration of industrial product and service shares, which represents a new solution-oriented approach for delivering value in use to the customer during the whole life cycle of a product [3]. However, the present researches about IPS2 are mainly focused on basic concepts, business models, value chain and operational scheme design of IPS2 [4–6]. How to connect these theories with the real operations in industry is still not be solved.

Recent years, the fast development of communication technologies, Internet of information, Internet of things, cloud computing and big data analytics have changed

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the objective internal and external environment for IPS2 development. There is a trend for integration of products, services, sensors, and the Internet, which has already been discussed as Cyber-Physical Systems (CPS) [7, 8]. CPS may bring a breakthrough in the development of IPS2.

This work is based on systematic investigation during project cooperation with three typical IPS2 companies in three different industries (construction machinery, elevator and power equipment) in eastern China, including. Those companies are trying to establish intellectualized industrial product service systems by integrating CPS, which are defined as intelligent IPS2 in this work. The research is trying to figure out a general framework and maturity model for intelligent IPS2.

Contents of this work are organized as follows. An introduction and a brief review of present work about IPS2 and CPS are carried out to clarify related concepts and depict state of the art in Sects. 1 and 2. Then a framework of CPS integrated intelligent IPS2 is proposed in Sects. 3 and 4, which contains three procedures, including system decomposition of intelligent IPS2, intellectualization process of IPS2 by integrating CPS, and then a general architecture of CPS supporting Intellectualization of IPS2. Last, the discussions and conclusions are offered in Sect. 6.

2 Related Work About CPS

A CPS is a system of collaborating computational elements controlling physical entities. Embedded computers and networks monitor and control the physical processes, usually with feedback loops where physical processes affect computations and vice versa [9]. The notion is closely tied to concepts of robotics and sensor networks with intelligence mechanisms proper of computational intelligence leading the pathway. Ongoing advances in science and engineering will improve the link between computational and physical elements by means of intelligent mechanisms, dramatically increasing the adaptability, autonomy, efficiency, functionality, reliability, safety, and usability of cyber-physical systems [10]. Today, a precursor generation of CPS can be found in areas as diverse as aerospace, automotive, chemical processes, civil infrastructure, energy, healthcare, manufacturing, transportation, entertainment, and consumer appliances.

The emergence of CPS provides whole new viewpoints and approaches for IPS2 construction. The improvements of information, automation, sensing and artificial intelligent technologies have changed the way of contacting, interacting and problem solving. And now, it's also beginning to change traditional business models. As mentioned above, while CPS has been widely applied in improving product design, manufacturing intelligence and other areas, CPS is rarely studied to support IPS2 intelligence.

Technologies will offer new opportunities for companies to provide novel products and services [11]. We believe the advent of CPS will enhance and accelerate the process [12]. So far, there have been some researches using information technologies to help improve the operational performance of service tasks. Zhu et al. [13] proposed a web-based product service system for aerospace maintenance, repair and overhaul services. Zhang et al. [14] offered a framework for design knowledge management and

reuse for product service systems in construction machinery industry. Teixeira et al. [15] tried to figure out a novel framework linking prognostics and health Management and product–service systems using online simulation. Selak et al. [16] presented a condition monitoring and fault diagnostics (CMFD) system for hydropower plants (HPP). Though those researches about information technology applications in supporting product service systems have been conducted, none of them have given a systematic framework of how information technologies, especially CPS, can be integrated with IPS2.

3 Framework Decomposition of Intelligent IPS2

An intelligent IPS2 firstly should be a product service system, which means that the basic value co-creation network should be built up according to the IPS2 business model. Based on the summary of investigation in several different industries and literature review, a framework of intelligent IPS2 is proposed, as shown in Fig. 1. The framework consists of seven parts, namely customer needs centered product lifecycle, stakeholders, service abilities, business models, cyber physical system, supporting

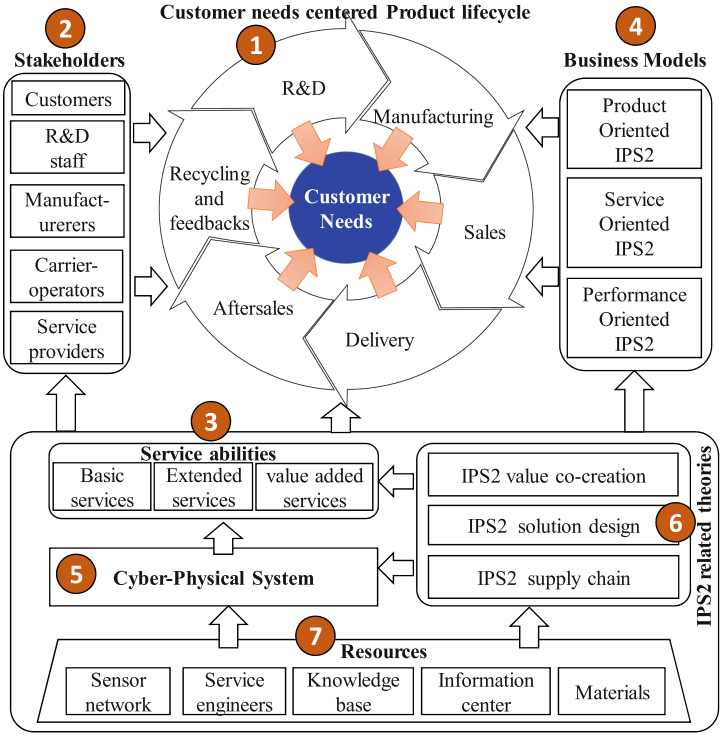

Fig. 1. The proposed framework of Intelligent IPS2 integrating CPS

theories and resources. The coordination of these modules is the basis for the construction and normal operation of intelligent IPS2.

Customer Needs Centered Product Lifecycle Under Service-Dominant Logic. Traditional understanding of IPS2 value chain mainly focuses on the after sales procedures. In this paper, based on the work of Aurich et al. [17, 18], Takata and Umeda [19], it is extended to the whole lifecycle of products with customers participated in every stage, including product R&D, manufacturing, sales, delivery, after sales and recycling. Characters and requirements in other procedures of the product lifecycle are also developed, which could be found in Table 1.

Table 1. Service characters and requirements in the full product lifecycle

Product lifecycle	Requirements in service-dominant logic
R&D	Module design for manufacturing and after sales services
	Standard interface and port for upgrading and expand
	Interaction module for service request and feedback
	Systems and tools allowing customer participated design
Manufacturing	On-demand personalized manufacturing
	Customer participated manufacturing
	Manufacturing to service orders
Sales	Customer behavior and needs based on market segmentation
	New contract modes: Leasing, performance contracting, etc.
	Products and services trial experience and direct selling
	Configurable purchase scheme
	Online to offline sales mode
Delivery	Shared supply network
	Visualized delivery information
	controllable delivery process
After sales	Product maintenance, repair, etc.
	Product upgrading, reforming, etc.
	Remote monitoring, fault alarm, etc.
	Financial leasing, project consulting, data service, etc.
Recycling & feedbacks	Direct feedbacks from customers or users
	Harmless treatment
	Product recycling tracing
	Remanufacturing

Stakeholders. In an intelligent IPS2, stakeholders generally include customers (or users), R&D staff, manufacturers, carrier operators, all kinds of service providers and other related roles participating throughout the lifecycle of products. Different industries may have different stakeholder constitution. But under the notion of IPS2, all stakeholders are supposed to cooperate as a network for value co-creation. Value co-creation is realized through work flow reconfiguration and business model innovation other than simple transaction and compromise.

Service Abilities. With all the resources integrated and CPS supporting, three categories of service packages or service abilities, including basic services, extended services and value added services, can be configured and provided according to specific needs of different customers. Basic services are the core of IPS2, then follows extended services in the middle layer, and value added services in the outermost layer. Characters and examples of different service categories are offered in Table 2.

Table 2. Three layers of service category

Service category	Characters	Examples
Basic services	Services offered to ensure the normal operation or quality of products	Product maintenance, spare parts replacement, etc.
Extended services	Services offered to extend or upgrade basic functions or structure of products	Remote monitoring, fault alarm, software updating, hardware reforming, etc.
Value added services	Senior services offered to help customer extend ability or business scope	Finance leasing, project consulting, data service, etc.

IPS2 Business Models. Generally, existing business models of IPS2 basically can be summarized into three categories [4, 20], which are product oriented IPS2, use oriented IPS2 and performance oriented IPS2, which are explained in detail in Table 3. In the paradigm of service-dominant logic and CPS integration, service and performance oriented IPS2 are becoming much more popular. The supporting of CPS accelerates the evolvement of the transformation from product based business models to service based business models.

Table 3. Three basic business models of IPS2

Business model	Characters	Examples
Product oriented IPS2	The manufacturers provide products and related services to the consumers who have the ownership of products	Maintenance, repair, distribution, reuse, recycling, training and consulting
Use oriented IPS2	Manufacturers who have the ownership of products provide customers with the usage and function of products	Product rental, leasing or sharing of passenger cars, air conditioner, construction machinery
Performance oriented IPS2	Manufacturers offer a customized mix of services to guarantee a certain result or capability instead of a product and the customers pay only for the performance	Energy performance contracting, Compressed air supplying contract, all-inclusive printing service, etc.

Cyber Physical System. CPS is the key factor in the intellectualization process of IPS2. CPS integrates all kinds of resources and packages them as services and release them automatically or autonomously. Detailed research about how CPS interacts with IPS2 and structure of CPS will be introduced in the following Sect. 4.

Related Supporting Theories. Apart from CPS, theories about directing the transformation of traditional companies to service based business models should be proposed and developed. Those theories can be categorized from three dimensions. The first are theories about helping figure out the mechanism of value network and value creation in IPS2. The second are those supporting IPS2 scheme design to meet customer needs as far as possible. The third are from the operational layer that direct IPS2 supply chain in order to improve the efficiency of service supplying and cut down the costs. All those theories should be combined together forming a theoretical system to support service ability fostering, service modes innovation, service workflow optimization and finally value co-creation.

Service Resources. Service resources are basic support for the operation of intelligent manufacturing. Service resources can be divided into two kinds, which are physical resources and virtual resources. Different from traditional IPS2, physical resources get upgraded and are able to be connected to the network via the embedded intelligent modules, including bar codes, chips, RF wireless module or other sensors. With the intelligent module, these physical resources are packaged as virtual resources, which can be perceived, managed, dispatch and even controlled remotely through the CPS. The virtual cyber system and the real physical system will be operated in two parallel spaces with precise synchronization.

4 Intellectualization Process of IPS2 by Integrating CPS

CPS helps IPS2 to enhance the loose relationships between stakeholders and resources, and to be closed integrated network connections. The purpose of integrating IPS2 with CPS is to improve the operational efficiency and accelerate the process of value co-creation in following ways:

Service Process Automation. With CPS integrated, customer needs and product usage data can be obtained directly. Service needs can be fast responded automatically. Meanwhile, orders from customers and pre-services forecasted from data statistics are able to be processed automatically. Proactive services become a mainstream that customer needs can be satisfied just at the right time instead of passive service offered after serious problems occur with customer complains.

Service Activity Autonomy. Both users and products can be served by themselves with CPS supporting. Products can upgrade their software automatically, or even self-diagnosis and self-healing when hardware failure or software crash occur. Users can learn new skills and get technical support with the help of embedded interactive guide software. Fast developing artificial intelligence will enhance and accelerate this trend of CPS application in intelligent IPS2 significantly.

Service Resource Integration. Under the circumstances of Internet of information and things, those supportive virtual and physical resources can be distributed in a more efficient way. Information of service needs, resource allocation and amounts gets integrated seamlessly. And meanwhile, physical resources are shared and planed with centralized management, so that the inventory, risks, costs and wastes can be minimized towards stable and sustainable operation.

5 Architecture for CPS Supported Intellectualization of IPS2

A general architecture of CPS supported intellectualization of IPS2 is proposed as depicted in Fig. 2, which is constructed by 5 layers. Descriptions of organization and function in each layer from bottom to top are as follows.

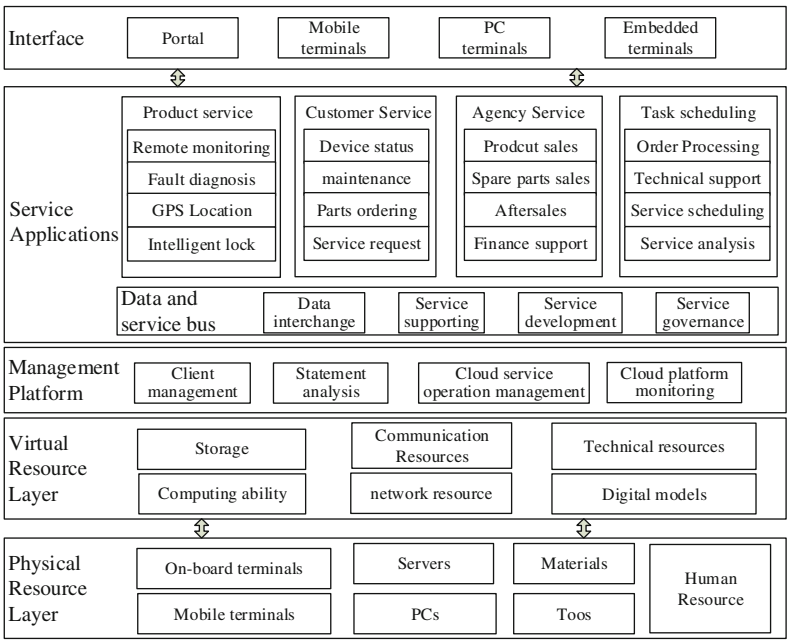

Fig. 2. A general architecture for CPS supported intellectualization of IPS2

(a) Physical resource layer: With the support of embedded cloud terminal technology and Internet of things, physical resources, including equipment, tools, materials, engineers and so on, are able to be connected to the network. Meanwhile, connection interfaces for cloud services virtual resource packaging and invocation are also provided in this layer.

(b) Virtual resource layer: In this layer, service resources connected to the network are collected as virtual service resources. Then, they would be packaged as cloud service using tools of cloud service defining and virtualization, and released to cloud service center through cloud management platform. This layer provides functions and virtual resources including storage ability, techniques base, computing ability, communication resources, network resources, digital model library and so on.
(c) Management platform: As the console of cloud service, management platform is an important support for management staff to monitor, supervise, analyze and optimize cloud services. Cloud basic management covers the function of platform service scheduling and distributing. Cloud platform monitoring is for the real-time management of platform performance indicators. Cloud platform operation management is developed for supporting resource distribution and tasks assignment.
(d) Service layer: This layer integrates data and service bus of the cloud platform and core service packages. Comprehensive intelligence service for customers, distribute agents, equipment operators, service engineers are provided from this layer.
(e) Interface layer: Base on cloud service platform, users can login through multiple log modes and terminals, while experiencing the same service applications. Services can be invoked form portal website, on-board terminals, mobile terminals, PC terminals and other approaches.

6 Discussions and Conclusions

The servitization trend of manufacturing industry is irreversible. Under this circumstance, the integration of CPS in IPS2 have been proved to be effective in improving service efficiency and reducing service costs. Based on the summary of investigation of several typical servitization industry, we found that companies in these industries are trying to build their own smart Industrial Product Service Systems by integrating CPS.

A general framework of intelligent IPS2 including 7 basic modules is proposed to guide the service transformation for manufacturing companies. We consider that the intellectualization of IPS2 by integrating CPS can be realized with three approaches, which are service process automation, service activity autonomy and service resource integration, respectively. In the meantime, the general five-layer architecture of CPS supporting intelligent IPS2 is also presented. Companies can make a customized version based on this proposed general architecture according to their own characteristics and particularities.

Those main findings presented in this work, have been validated with several cooperation projects. However, the research in this paper still needs improvements. Achievements of this work are studied from large groups or companies, so how these approaches can be applied to small and medium sized companies will be a new direction for future research.

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