

Industrie 4.0: Enabling Technologies

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Abstract—With the development of industries, we have realized the third industrial revolution. Following the development of Cyber-Physical Systems (CPS), industrial wireless network and some other enabling technologies, the fourth industrial revolution is being gradually rolled out. This paper presents an overview of the background, concept, basic methods, major technologies and application scenarios for industrie 4.0. In our view, industrie 4.0 as an abstract concept can closely integrate the physical world with virtual world. This strategy of industrie 4.0 will lead to more and more people coming to participate in the manufacturing process and further popularize our products through CPS technology. The typical approach for industrie 4.0 is the social manufacturing. In fact, the social manufacturing can directly link our customers' need and our industries, but it must be based on the enabling technologies, such as embedded systems, wireless sensor network, industrial robots, 3D printing, cloud computing, and big data. Therefore, this paper in detail explains these concepts, advantages and the relations to industries. We can foresee that our life will be changed to be more efficient, fast, safe and convenient due to the development of industrie 4.0 in the near future.

Keywords—Industrie 4.0; cyber-physical systems; industrial wireless network; social manufacturing; cloud computing; big data

I. INTRODUCTION

As we know, Germany has one of the most competitive manufacturing industries in the world. This is due to its ability to manage complex industrial process where different tasks are performed by different partners in different geographical locations. It has been successfully employing Information and Communication Technology (ICT) to do this for several decades. As we know, approximately 90 percent of all industrial manufacturing chains are already supported by ICT. The Information Technology (IT) evolution has brought about a radical transformation of the world in which we live and work, with an impact comparable to that of mechanization and electricity in the first and second industrial revolutions. The evolution of PCs into smart devices has been accompanied by a trend for more and more IT infrastructure and services to be provided through smart networks. In conjunction with ever greater miniaturization and the unstoppable march of the internet, this trend is ushering in a world where ubiquitous computing is becoming a reality. Powerful, autonomous microcomputers (e.g., embedded systems) are increasingly being wirelessly networked with each other and with the internet [1]. This has resulted in the convergence of the physical world and the virtual world (cyberspace) in the form of Cyber-Physical Systems (CPS) [2].

With the introduction of the new internet protocol IPv6 in 2012, now we have sufficient addresses available to enable universal products direct networking of smart objects via the internet. This means that for the first time ever it is now possible to search network resources, information, objects and people to create the internet of things and services. The effects of this phenomenon will also be felt by industry. Then we can make everyone directly participate in the production process through internet, which is the shape of social manufacturing. In the realm of manufacturing, this technological evolution can be described as the fourth stage of industrialisation, or industrie 4.0 (see Fig. 1).

In this article, we elaborate the transformation of commercial production and the coming of social manufacturing, largely based on the background of industrie 4.0. In addition, we use some key enabling technologies to exhibit their basic methods and influences to the industrial revolution. Finally, we put forward the conclusion that industrie 4.0 with the support of the enabling technologies will promote the industrial development and transformation.

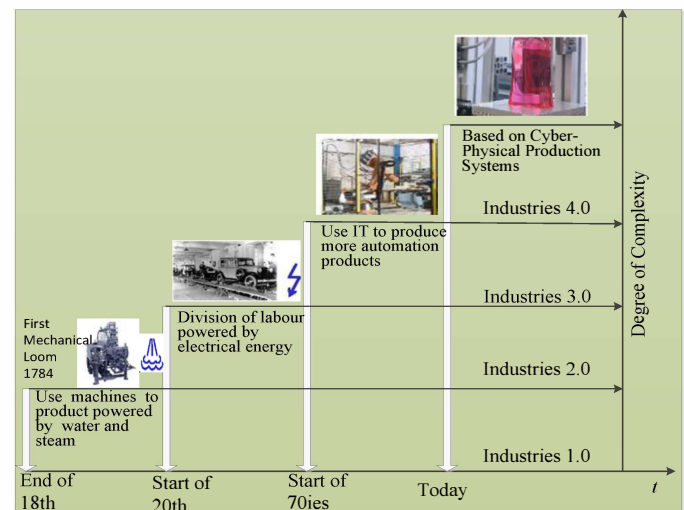


Fig. 1. The four industrial revolution history [3]

II. MOTIVATION

Due to Chinese lack of workers and energy crisis, the manufacture should develop toward smart production. The concept industrie 4.0 is based on intelligent manufacturing-oriented fourth industrial revolution, or a revolutionary production method [3]. This strategy aims to take full advantage of ICT combining with CPS to make the manufacturing process

be transformed to intelligence [4-6]. The basic model of distributed control changes enhanced by centralized control, the goal is to create a highly flexible personalized and digitized production model of products and services. Especially, after the 3D printing technology becomes popular, more and more traditional production mode will be changed. A new model of social manufacturing will become an important part of industry. In this model, traditional industry boundaries will disappear, and new domains and cooperation form play a role. The general public will participate in the design, sale and improve our products. The process of creating new value will be changed; industrial chains division will be restructured. Advocating Internet of Things and Services (ITS) aims to link production and sales, and achieve production automation under the Machine to Machine (M2M) operational structure [7-9]. Then, we can achieve smart production, green production and urban production.

Rolling out industrie 4.0 will not only strengthen factories' competitive position, but drive solutions to both global challenges (e.g. resource and energy efficiency) and national challenges (e.g. managing demographic change). What's more, it will change our traditional way of manufacturing and take us more convenient and green product. Especially, in the mode of 3D printing, the process of joining materials to make objects from 3D model data, usually layer upon layer, as opposed to subtractive manufacturing technologies. In this way, we may save so much material and produce less industrial waste. However, it is inevitable to affect technological innovations within their social cultural context, since cultural and social changes are also major drivers of innovation in their own right. This will in turn have significant implications for productivity by optimizing the relationship between technological and social innovation processes.

III. ENABLING TECHNOLOGIES

The enabling technologies refer to one or a series of wide and multidisciplinary characteristics application to complete tasks. Industrie 4.0 is to set up intelligent manufacturing and intelligent factory based on CPS. So it is inevitable to use these technologies to link the internet, transform orders, pick-up information, store data, etc. Under the mutual integration and optimization of enabling technologies, it will become more simple, convenient and accurate to production, processing and molding [10]. What's more, with these technologies to collect, convey, and process people's idea, and combine the customer's need with production chains, it will be better to meet people's needs.

Industrie 4.0 has two main themes, one is intelligent factory, which is aim to study intelligent production system and accomplish networked distributed production facilities. The other is intelligent manufacturing, which is mainly related to the entire enterprise production logistics management, human-computer interaction and 3D printing technology in industrial processes. Under these two objectives, we need to complete the efforts in four areas: new methods, new technologies, new demands, and new models.

A. Realizing Smart Factory

The intelligent factory means distributed equipment with some smart production that forms a highly intelligent organism in the realization of data exchange, to achieve the integration of virtual world and the physical world. Compared with previous

modes, intelligent factory is to significantly improve resource utilization, greatly reduce the storage and distribution cycle of personalized production and the real-time image display products, which is as a tie to link the production with real-time customers' demand.

But we must note that intelligent factory doesn't mean unmanned work shop. In the mode of smart factory, all of the people from everywhere can take part in the production process via internet and some other channels. Human is the core to achieve interaction, make decision, realize process optimization and play an important role in the design, installation, updating and maintenance of Cyber-Physical Production System (CPPS), Internet of Things (IoT) and cloud [11, 12]. This is a way of social manufacturing. So, smart factories will coexist in harmony with human.

1) Embedded Design

The intelligent factory aims to achieve the integration of virtual world and the physical world based on CPS, IoT and cloud [13]. IoT is an application-oriented engineering technology, which combines with sensors technology, computer technology and network technology [14]. In our daily life, the smart sensors, wireless network, information display and processing that are used in producing departments all contain a large number of embedded systems technology and application. The developing smart sensor chip technology and embedded software system that will be used to detect and transform information in the factories are the two key development directions which are closely related to the development of embedded system. Actually, compared with traditional embedded system, IoT is a new embedded application which has more and complex levels [15]. IoT has not only real-time applications displayed on the perception layer but data processing and analysis used in application layer [16].

Today, the social informatization is gradually accelerating. The embedded system and network application are becoming a part of our life. In production, embedded system is an important support to industrial infrastructure [17]. Now, approximately any kinds of production chains are using embedded system to realize auto-control and communication. The main object of embedded system applications is that these equipment and products need digitization, intelligence and network. The embedded system applications can not only improve our quality of life, but change the way of traditional industries' production, operation and service. Then it will obtain huge social and economic benefit for enterprises. For another part, what we want is to realize any part of the factory can be set to autosensing, auto-selecting and auto-detecting, which is just the advantage of embedded system [18].

2) Industrial Wireless Network

With the deepening development of enterprise information technology, and business model's innovation, more and more professional work is associated with the network [19]. So, if we carry out our companies' operation and service deployment to achieve big breakthrough, then we need users, applications and professional work to integrate with network. But, it will inevitable to take some new challenge and advantages to the development of wireless network: a) globalization of business expansion and the structure of headquarters and diversion combine with diversified partner, which need every enterprises to realize interconnection through network; b) globalization of

business expansion and the structure of headquarters and diversion combine with diversified partner, which need every enterprises to realize interconnection through network; c) the use of cloud manufacturing, IoT and multimedia service need industrial campus network to be faster, safer and have better quality; d) the increasing complexity of network needs factories have more professional deployment and more sophisticated strategy; e) traditional security protection is inevitable becoming the weakness of network. So it cannot fulfill customers' need of information's security protection. And we must find some new way to strengthen the security protection; f) the diversification terminal and complex scene of application need enterprise network can be accessed by any terminal anywhere; g) enterprise network needs to carry business-critical 7×24 hours of uninterrupted operation with high reliable requirements; enterprise network needs to establish an efficient and simple network to avoid energy consumption of the redundancy device and link; and h) campus networks often need to adjust the coverage, range, bandwidth and business properties, so it needs to be able to smoothly adapt to these adjustments.

In the cloud manufacturing and IoT era, it is necessary to provide Terminal-to-Terminal (T2T) network service for enterprises to help them deal with these challenges and accelerate globalization and informatization reform. On the other hand, industrial wireless networks (see Fig. 2) are the essential technology to link any part of the factories and make them integrate to complete our task. It is no exaggeration to say, industrial wireless network is the most key point to realize intelligence. It is the media to link our equipment and help them to communicate with each other and exchange their data [20]. Using stable and energy-efficient wireless network will help us to work efficient and convenient.

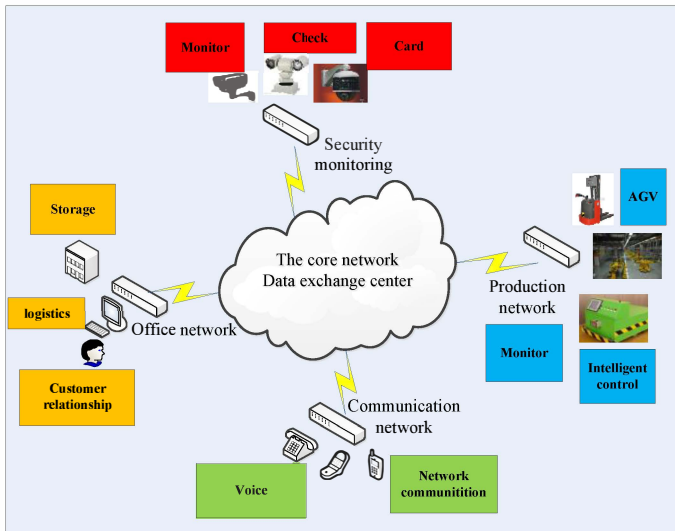


Fig. 2. The use of industrial wireless network

3) Automated Guided Vehicle (AGV)

Industrial revolution promotes the progress of human civilization, and robots promote the progress of industrial revolution. The formation of intelligent factory is part of intelligent revolution, and wireless AGV is an important part of intelligent factory [21]. AGV are automatic machines that make a great contribution to factories in transport, weightlifting, detection, etc. Now, with the integration of ICT, AGV becomes more and more intelligent. And it will take us much more convenient to use AGV: a) it can increase the degree of

automation and efficiency; b) reduce labor costs, especially in handling with large products and goods which have some corrosive, hazardous material. Then we can increase benefit; and c) improve efficiency. It is used to drive truck to handle goods, which is inconvenient to shuttling in small space. And AGV is outstanding in this regard.

AGV is the real sense of robot that integrates the technology of robot, intelligent equipment and ICT. It is a typical representative of intelligent manufacturing to solve the transformation process between factories, workshop and production line to manufacturing realization. It will also make our work environment fast and safe.

4) Integration and Optimization

Intelligent factory is a part of social manufacturing. It is the side that we can use to search crowdsourcing and automatic production. Intelligent factories contain embedded technology, wireless network technology and some other technologies. It is a big platform which is composed of Information Facility Systems (IFS), Information Application Systems (IAS), Equipment Management System (EMS) and Public Safety System (PSS) through the way of modernized IT technology, wireless network and production system. Intelligent factories improve the industrial chain, to provide security, stable, efficient, high-quality, energy, environmental and healthful production environment [22].

The development of intelligent factories is a new direction of industrie 4.0. And it has some manifest advantages that are showing as follows:

- a) *System with independent capability*: The system can collect and analyze inside and outside information to programming their behavior.
- b) *Practice a whole visual technology*: Combine with signal processing, reasoning, estimating, simulation and multimedia technology to show the design and manufacturing process truly.
- c) *Coordination, reorganization and expansion characteristics*: Any part of the system can make the best system structure according to their own tasks.
- d) *Self-learning and maintenance capabilities*: Through its self-learning technology to supplement, update and diagnose the system during production. Then it can solve the problem or request the personnel to handle.
- e) *Human-computer coexistence system*: Human and computer coordinate and cooperate with each other to play their respective advantages.

B. Realizing Intelligent Production and Management

Intelligent manufacturing is another direction of industrie 4.0. It is mainly related to production and logistics management, human-computer interaction, and 3D printing technology. Intelligent manufacturing is to fabricate product that integrate the informatization and industrialization. In recent years, it has been a profound transformation in information technology and industrial areas. Cloud computing, big data, mobile internet and social network have changed the traditional mode of thinking, and took information technology to even bigger stage to fulfill the needs of industrial development. In industrial areas, from industrial wireless network to social manufacturing, there are more and more information technologies merging into

techniques of automation which even increase the intelligence of industries. What's more, the 3D printing has been produced and became popular, which has made a big transform to manufacturing in the way of changing the mode of reduction production to additive production [23, 24]. Using social network and 3D printing technology, anyone can participate in the process of production chain and any computer may become a small factory. With the transformation of information and manufacturing, intelligent manufacturing has reached a new level of development [25].

1) Industrial Cloud

As we know, cloud computing is a service-oriented computing mode. In recent years, it is very popular and becomes mature gradually. We can all know that, this is information age and the most important is data. Every day, we will produce countless data from all kinds of equipment and users. We want to realize social manufacturing, but the first thing is searching from these crowdsourcing to find the social demand, which is impossible to use traditional computing. Cloud computing can manage a lot of virtual computing data and make up a resource pool that can be used to provide on-demand service for personal and business users through autonomous and heterogeneous service mode on internet. It has some features, such as large scale, virtualization, versatility, scalability, and on-demand service (see Fig. 3).

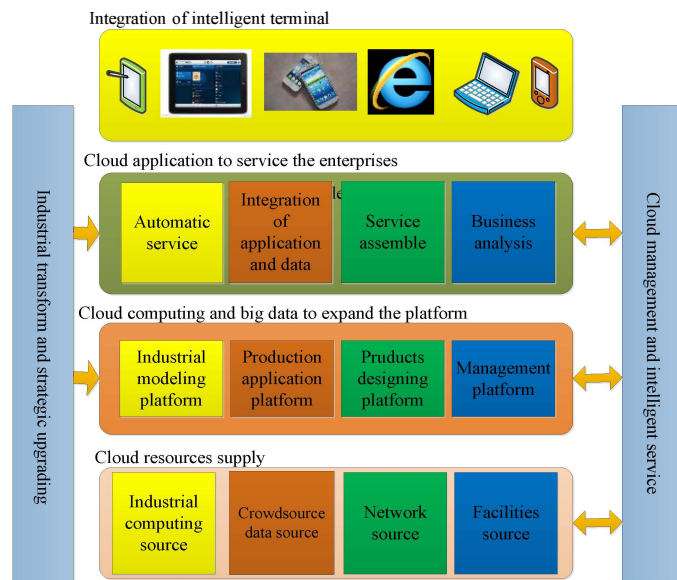


Fig. 3. Cloud technology supports the industrial transformation [26]

In another way, cloud computing can also make a great contribution to smart tools. With the development of intelligent production, many new kinds of smart devices and terminals are used in production. We can find one or more smart terminals to do their jobs everywhere in the factory. Cloud computing will greatly change smart device's hardware, software and industrial chain [27]. It accelerates hardware's upgrade and differentiation to bring more accurate and convenient machines and tools to handle different problem [28]. On the other hand, it enhances industrial devices' processing power, gives a new way to advance storage capacity and strengthen devices' hardware requirements when it is connected to the internet. Then, intelligent terminals are developing toward multi-screen and have shown integration trend. What's more, it has begun to arise cloud service and cloud mode in operating system, which

promotes the increase of application and strengthens software's function [29]. Cloud computing brings a new trend of the development of structure and changes applications' frame. It makes applications develop from the built-in single apps, local apps and terminal apps to apps with cloud platform, online apps and cross terminal apps. At the same time, with the development of production capacity and the application grow with each passing day, more and more data that are hard to searching and using will be produced, so it is necessary to use cloud computing to solve it and find our needful data faster and more convenient.

On the time of intelligent manufacturing, cloud computing is an important support to industry. The aim of industries is to realize intelligent fabrication and social manufacturing, but the key point of these is to realize social computing and upgrade our machine to be smarter. This is just the advantage domain of cloud computing.

2) Industrial Big Data

Big data needs new processing mode to have more decision-making power, insight and process optimization ability. Big data and cloud computing are the two sides of one coin that are inseparable. Big data can't be operated by only one computer, and it must use distributed architecture to handle this. Big data's feature is Software as a Service (SaaS) which must use distributed processing, Platform as a Service (PaaS), cloud storage and Infrastructure as a Service (IaaS) [30].

With the development of CPS and intelligent manufacturing, more and more data is produced from every machine in the factories and public, more security and convenient data is needed. So, the improvement of industrial big data is essential. It will take a new era of industrial innovation and revolution. Firstly, industrial big data will help enterprises to search demand through excavating and analysing these customer dynamic data. Secondly, industrial big data can be used to diagnose and predict product, which is good for after-sale service and product improvement. Thirdly, industrial big data is a very important part of industrial IoT to synchronous data. So, we can use it to improve our production process and find energy anomaly timely to achieve the purpose of reducing energy consumption. The last, industrial big data will help us to analyse and optimize industrial supply chain. This is very important to enhance the efficiency of storage, distribution and sales and saving cost [31, 32].

Actually, intelligent factories are new intelligent manufacturing system that contains future advanced manufacturing technology based on arrangement and application in big data management. Intelligent industries aim to merge the sense of perception of environment into industrial devices through ubiquitous network technology to greatly improve the manufacturing efficiency, improve products' quality, decrease cost, decrease resource consumption and develop traditional industry toward intelligent mode. At the same time, big data is very important reference in hardware manufacturing and software manufacturing.

3) Social Networks

Social network is the base of social manufacturing which is a form of industrie 4.0. Only if the social network has deepened development that we will have enough idea, projects, opinion and feedback to produce on-demand products. The biggest characteristic of social manufacturing is that everyone can

directly transforming their idea into products, which is so called mind-to-products. Social manufacturing leads everyone can take part in the design, improvement, and marketing of their products through social media (see Fig. 4). They can even share their products' profit. In a word, social manufacturing is the strategy that needs 3D printing, network technology and social media to make their products and mode become real time; individualization and economization through integrating online behavior and offline behavior (see Fig. 5).

In the environment of social manufacturing, with the social network, a lot of 3D printers will format manufacturing network, which can be integrated with IoT and logistic network to compose a big social manufacturing system that can fulfill customers' on-time demand [33].

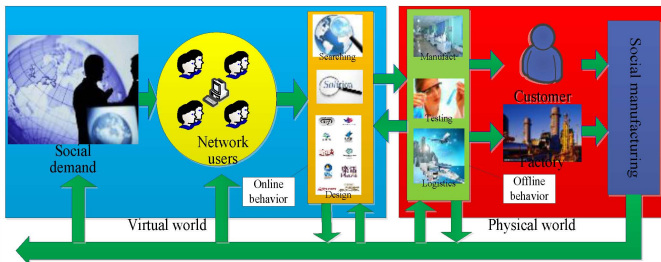


Fig. 4. The integration of social demand and social manufacturing [34]

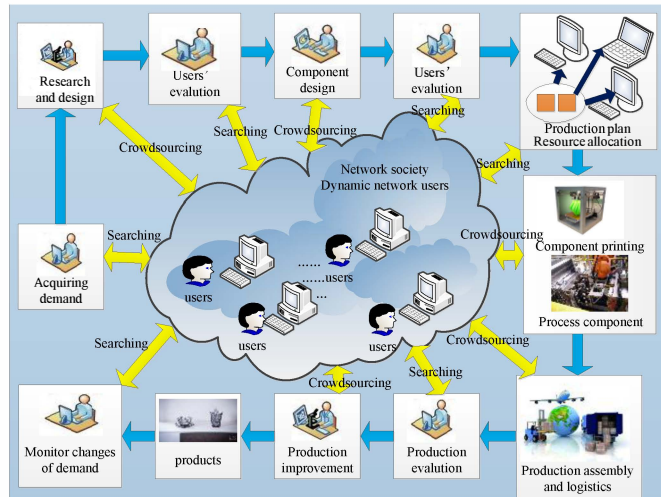


Fig. 5. The mode of social manufacturing [34]

IV. OUTLOOK

Industrie 4.0 reflects the change of manufacture from centralized mode to distributed mode. It is the progress of technology that makes the traditional production process theory subversion comes true. Meanwhile, distributed intelligent manufacturing represents the interactive relationship between virtual world and real world and plays an important role in establish CPS. Futhermore, Industrial production machineries are not just processing the products but communicating with machines to teach them how to operate through communication system.

Industrie 4.0 will set up a new manufacturing mode, in which its products and services are high flexible, personalized and economical. In this mode of social manufacturing, traditional industry boundaries will disappear; some new activity and cooperation forms will come into being. The progress of creating new value will be changed and industrial

chain will be recombined. Meanwhile, in this mode, the most core of social manufacturing is social computing and we must transform traditional factories to these industries that can actively perceive and response to user' large-scale personalized needs. At that time, public will energetically participate in the industrial chain and send their demands in the form of crowdsourcing. And, the factories will be just to find the demands and fulfill their needs [35].

What's more, in industrie 4.0, it will be possible to simulate all the steps in the manufacturing process and depict their influence on production. This will include simulation of inventory levels, transport and logistics, the ability to track the usage history of components that have already been used in production and provision of information relating to how long components can be kept before they expire. This will enable product-specific set-up costs to be calculated and reconfiguration of production resources to be kept to a minimum. It will also be possible to assess the relevant risks and simulate the different costs and margins of alternative suppliers, including simulation of the environmental impact associated with using one supplier over another. Extensive networking of manufacturing systems will make it possible to analyze alternative suppliers and their capacity in real time. It will be able to contact and engage suppliers directly via the appropriate secure channels in the supplier cloud [36, 37].

V. CONCLUSIONS

In this article, we use so many words to demonstrate that in the background of industrie 4.0, these enable technologies will play an important role in the development and transformation of traditional industry. Our production chain will improve the mode of social manufacturing. In this mode, customers can directly link to the enterprise and participate into the production chain. Social demand can be combined with social production ability in real time and efficiently. Moreover, every computer that can access the internet will become a small factory combine with 3D printing technology. The idea of mind-to-product will come true. And, the most valuable competitiveness is to find social demand. Social searching will become the base of social demand and can be transformed to manufacture. Then, it will cause consumption. Social manufacturing can be able to greatly stimulate the social demand, improve the participation of whole society effectively and strengthen the competitiveness of Chinese manufacturing industry. Moreover, it will use these new ways, new technologies, new needs and new mode to make our world toward smart manufacturing, green manufacturing and urban manufacturing.

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