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A Preliminary Study on the Integration of Intelligent Manufacturing and Industrial Internet

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Abstract: Data-driven intelligence is the essence for both intelligent manufacturing and Industrial Internet. The integration of intelligent manufacturing and Industrial Internet promotes the revolution and upgrades of traditional industries' key areas and develops research support for basic capabilities: chips, basic software, algorithms, and mechanism models. This study analyzes the macro demands for integration in China, explaining the development status and trends of intelligent manufacturing and Industrial Internet industries, and elaborates on China's integration opportunities and challenges. Generally, we suggest developing emerging areas of the Industrial Internet industry, focusing on the key upstream links in intelligent manufacturing to meet advanced international levels in traditional fields. Precisely for the Industrial Internet industry and its integration with manufacturing, China expects to make breakthroughs in the core areas, seizing opportunities to develop emerging areas and strengthening its efforts in the uncompetitive areas. Moreover, it is expected to establish an industrial ecology with all entities' full participation, enhance skill training, and accelerate technological breakthroughs, so as to provide rapid development of China's intelligent manufacturing and Industrial Internet industries that guarantees basic industrial transformation and upgrades.
Keywords: intelligent manufacturing; Industrial Internet; industry chain; intelligent equipment; industrial software

1 Introduction

The world is currently facing an industrial revolution, in which the manufacturing industry plays an increasingly important role. However, the manufacturing industry is challenged by high production and operating costs and low-quality product and value—the high-quality development of the manufacturing industry depends largely on the intelligentization reforms. Besides the digital economy's future, the integration of industrial manufacturing and information technology (IT) exists, which promotes the traditional industries' revolution [1,2]. The following technological advancements drive significant changes in the traditional industries: strengthening the Internet through novel networks, accelerating the application innovation using cloud computing, promoting value mining through artificial intelligence (AI), and open-source boosting the ecosystem construction.

Major highly industrialized countries currently map out strategies for the intelligentization, upgradation, and development of the new manufacturing industry. With intelligent manufacturing and industrial Internet located at the core, a comprehensive policy system has been proposed to accelerate the development and seize through the

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industrial revolution. For example, in her leading role to prioritize IT innovation, the US published the *Advanced Manufacturing Partnership*, *National Strategic Plan for Advanced Manufacturing*, and *Strategy for American Leadership in Advanced Manufacturing*. Germany, the first to develop the Industry 4.0 Strategy [3,4], highlights the state-of-the-art applications of cyber-physical systems. It has released plans, such as the *New High-Tech Strategy for Germany (3.0)*, *National Industrial Strategy–2030*, and *Innovation of Transportation, Healthcare, Energy, and Manufacturing Driven by the Cyber-physical System*. China sees IT and industrial manufacturing integration as a principal factor of development. Recently, China published the *Intelligent Manufacturing Development Planning (2016–2020)* and the *Guiding Opinions of the State Council on Deepening the "Internet plus Advanced Manufacturing" and Developing the Industrial Internet*. In these reforms, intelligent manufacturing is considered a breakthrough by the national advanced manufacturing industry. The industrial Internet serves as a platform to promote industrial manufacturing's transformation and upgrade toward digitalization and intelligentization [5,6].

Intelligent manufacturing receives support from the industrial Internet, which occurs in various links, including design, production, manufacturing, management, and services. It is characterized by efficient decision-making, real-time dynamic optimization, and sensitive and agile response [7,8]. The industrial Internet relies on the connection between man, machine, and things to connect industrial factors, the industry chain, and the value chain. It motivates the construction of a new industrial manufacturing system for better service applications [9]. In principle, intelligent manufacturing and industrial Internet are data-driven intelligentization, and their integration improves one another [10]. A future-oriented approach helps to build an advanced informationized manufacturing system that takes the internetworking as the basis and the industrial Internet platform as the core. Creating a new manufacturing ecosystem impacts the development of China's manufacturing industry significantly [11]. The intelligent manufacturing and industrial Internet boost the emerging fission and upgrade the traditional industries' key sectors. Basic chips, software (open-source), algorithms, and mechanism models, are expected to be further expanded to build an industrial system that integrates the intelligent manufacturing and industrial Internet (Fig. 1).

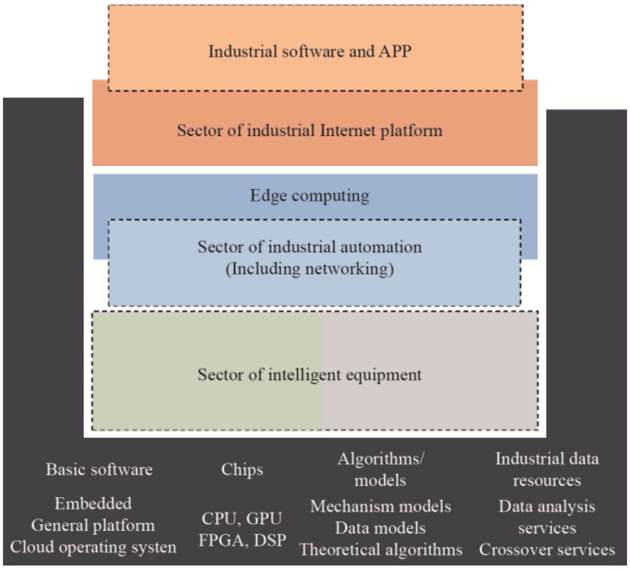

Fig. 1. Coupling relationship between intelligent manufacturing and the industrial Internet industrial system.
APP: application; CPU: central processing unit; GPU: graphics processing unit; FPGA: is field-programmable gate array; and DSP: digital signal processing.

This paper analyzes the integration development trends of intelligent manufacturing and industrial Internet in different countries based on the field's existing problems. Subsequently, the current status and trend of research on integration development are discussed in four components. The need of China, concerning the integration development of intelligent manufacturing and industrial Internet, is clarified. We discuss the development opportunities for the key links of the intelligent manufacturing industry chain. Based on China's current development status in this field, existing challenges and key problems are outlined, and suggestions are proposed to develop intelligent manufacturing and industrial Internet. The research findings can provide a theoretical reference for the transformation and upgrade of China's industrial manufacturing.

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2 Demand analysis of the integration development of intelligent manufacturing and industrial Internet

2.1 Intelligent manufacturing raises new requirements of the platform tools

2.1.1 Need for novel data management tools for the rapid growth of industrial data

As the concept of spatial extension of the industrial system deepens, the scope for collecting industrial data has been expanding. Thus, rapid growth occurs in both the number of types and scale of data. Reducing the management cost and increasing the storage reliability of the massive data requires new data management tools.

2.1.2 Need for the use of novel carriers of application innovation to promote enterprises' intelligent decision-making

The manufacturing enterprises also rely on massive data to achieve more advanced and precise management. As the industrial scenarios became more hierarchical and overlapped, barriers appear in data and knowledge across the industries. For this reason, the conventional application model no longer meets different needs across the enterprises/industries. The novel carriers' application model relies on the actual industrial data and abstract industrial knowledge. These carriers can combine with the platforms with intact functions to break the application innovation barriers and meet intelligent applications' rapid growth needs.

2.1.3 Need for new business interaction tools for the novel manufacturing mode

Due to high-speed products upgrade, manufacturing enterprises require a higher frequency of resource synergy and peer production. A better business interaction in terms of design, production, and management is expected between the enterprises to achieve the above goals. Thus, new interaction tools come into play, which primarily includes different systems characterized by high-efficiency integration.

2.2 Revolution of manufacturing industry model due to accelerating penetration of the information technology

Rapid advancement in IT promotes the manufacturing industry's digital upgrade. To promote digital upgrade, the manufacturing enterprises rely on the Internet to collect massive unstructured data from the equipment and production line. Cloud computing provides flexible and convenient software application environments that are reliable with cheap data storage capacities; besides, the data mining capacity can be enhanced by AI. The manufacturing enterprises respond to the market demands and integrate resources with high efficiency to organize production and operation by taking advantage of Internet platforms. All these promote collaboration in both sectors. The integration of information and manufacturing technology provides the impetus for the new economic model to penetrate and reform the industrial sector.

3 Development status of intelligent manufacturing and industrial Internet

The intelligent manufacturing and the industrial Internet industries represent two important pillars for the novel industrial manufacturing capacity system in the future. There are four components: high-end intelligent equipment, industrial automation, industrial software and applications, and industrial Internet platform.

3.1 High-end intelligent equipment

High-end market expansion of and basic technology research on the manufacturing equipment are further required, and intelligentization represents the ultimate for development. Intelligentization of the manufacturing equipment is the integration and fusion of advanced manufacturing technology, IT, and intelligent technology. The primary judgment criteria are whether the manufacturing equipment can perceive, analyze, make an inference, and make decisions and control. Intelligent manufacturing equipment is an important constituent of smart manufacturing. They include the hardware industrial infrastructure (e.g., industrial robots, numerically controlled machine tools, and additive manufacturing machines) as well as the detection equipment (e.g., intelligent control software systems and sensors).

Presently, China occupies a certain position in the low-end market of the intelligent equipment industry. China's share of the high-end market is still low. The two major weaknesses in the key technologies are basic processes and algorithms [12]. The problems of low innovative capacity, small market size, and unstable industrial basis still exist. For example, the Chinese products are generally located within the low- and middle-end market (like the transfer and spray-painting robots and low- and middle-end machine tools).

Remote monitoring and fault diagnosis technology of industrial robots are the research hotspots in this field. Asea Brown Boveri (ABB), a Swedish company, was the first to develop a service platform for remote monitoring of industrial robots and reduce the loss and the operating costs incurred by industrial robots' failure [13]. An American research team realized the remote monitoring of robotic arms by using the torque and temperature as the controlled quantity based on the analysis of failure features [14].

Currently, the intelligent control system market is dominated by large-scale international enterprises. For example, the European and American enterprises account for 74% of the world's top 50, while the American enterprises alone take 50% of the top 10. Foreign products occupy over 90% of the Chinese market of high-end numerically controlled machine tool control systems.

China has key technical weaknesses in important industrial facilities, such as detection equipment, control equipment, and core parts. The research and development (R&D) on the relevant products generally follow foreign countries' footsteps. As of the time of this paper compilation, China is lagging in terms of advancement and perspectives. Moreover, the low level of professional production and personal negligence are also factors restricting intelligent manufacturing development.

The trends of intelligentization and networking promote the development of equipment collaborative intelligence. New cores, links, and intelligent equipment industry entities constantly appear [15]. Synergy optimization is impossible without single-node enhancement. The fifth-generation (5G) wireless systems promote networking and intelligentization, as China's 5G equipment suppliers become important participants of the equipment industry. The AI chips are the core parts of intelligent equipment products. The Chinese enterprises in AI chips are mainly focused on autopilot and are now developing at great speed.

3.2 Industrial automation

Industrial automation is divided into many sectors, including industrial control, industrial network, and industrial sensors. The priority is to provide the products and solutions in sensing, control, and transmission, which support the intelligent manufacturing capacity at the operational technology (OT) level. China has succeeded in replacing some foreign products with domestic products. However, the control of the key market and technologies is still weak, and the foreign enterprises dominate the core products and standards.

Concerning the industrial control systems, the German enterprises remain the dominant power in the middle- and large-sized programmable logic controllers (PLC), with a global market share of 31%. Chinese enterprises only have a small part of the share for the small-sized PLC. On the technical level, foreign enterprises control microcontroller unit (MCU), digital signal processing (DSP), field-programmable gate array (FPGA), and other core components [16].

In the industrial network sector, foreign automation enterprises have already controlled the market and the network's core standards. Chinese enterprises occupy marginal links of this sector. The current market share situation has already solidified, with a little prospect of change in the short term.

In the industrial sensor sector, the United States, Japan, and Germany have collectively acquired about 60% of the global industrial share. Although the Chinese enterprises are making rapid progress, they only occupy 10% of the global market share. Large-scale foreign enterprises have almost established domination in the key technologies of core elements like the sensitive chips on the technical level. They are keeping a tight hold of the market. For example, in 2004, an American scientific research institution successfully developed the SiC piezoresistive pressure sensor with a 400°C working temperature [17]. Also, a Malaysian university developed a high-temperature pressure sensor in 2015 using 3C-SiC as the primary material. This sensor's working range was 5MPa, and the working temperature was as high as 500°C [18]. In 2017, the 49th Institute of China Electronics Technology Corporation developed a pressure sensor with an operating range of 100 MPa through the technical import and incremental innovation [19].

In the future, novel algorithms will support the morphological and functional reform of the products. Automation and cloud computing enterprises jointly facilitate industrial automation toward edge intelligence. On the industrial level, these enterprises shall comply with the trend of the technical development. The automation enterprises will lead and integrate the R&D of AI and consolidate their market position via the products' intelligent upgrade.

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3.3 Industrial software and applications

Industrial software is a collective term for various software types for the R&D design, production management, and operation management under the industrial domain. Currently, industrial software is undergoing a transition process from complex system software to a convenient platform. Industrial applications (APPs) have become the new form of industrial software. Industrial APPs, which are usually lightweight, are carriers of industrial knowledge and experience and operate at various industrial terminals to deal with specific business problems.

At present, China's industrial software sector faces the problems of R&D product design deficiency, small market size (but high growth rate), and lack of key technology accumulation. According to the released data, the top 10 computer-aided engineering (CAE) software commercially available in China are foreign manufacturers []. In 2015, the Chinese share of the global industrial APP market was 3.5%, though its growth rate (10.2%) exceeded the global level (0.47%).

In the sector of production control software, German enterprises still maintain a competitive edge. They have proposed fully integrated digital solutions based on the product lifecycle management architecture, thus realizing multi-layer information interaction in the manufacturing factories [20]. Chinese enterprises occupy a certain position in China's key sectors such as electricity, ferrous metallurgy, and the petrochemical industry [21, 22].

In the technical domain, Chinese enterprises do not master the CAE finite element method or the core function of geometric kernels of computer-aided design (CAD); they can only use these algorithms through authorization. Besides, little experience has been accumulated in the models of relevant sectors, and the existing models can only perform some basic functions with a lack of competence and flexibility.

Promoting industrial APP through software architecture optimization will become a new trend. The form of subscription will stand out because of comprehensive software cloudification. The software architecture technologies will materialize and represent the concepts of microservices, containerization, and DevOps. The complete cloudification phase of various industrial software in management, simulation design, and production control will soon surface.

3.4 Industrial Internet platform

The industrial Internet platform as an industrial cloud platform is envisioned to promote the digitization, networking, and intelligentization of the manufacturing industry. The industrial Internet platform is a service system that integrates the collection and analysis of massive data. It supports the elastic supply, extensive linking, and high-efficiency configuration of the manufacturing industry's resources [23]. The development environment targeting the current processing of big data is constructed to implement the modeling, digitization, and standardization of the relevant abstract knowledge and experience. The resource utilization in such links as design, manufacturing, and operation management of the industrial production is optimized to create a new ecology of manufacturing industry reform that moves toward resource integration and win-win cooperation [24].

Many industries and enterprises in developed countries have opted for the industrial Internet platform as the primary strategic direction and commenced deploying and constructing a platform that adapts to their features. For example, the Predix Platform by General Electric serves as a bridge between the IT and OT data of the enterprises. Similarly, MindSphere by Siemens possesses the features of an IoT operating system by targeting the demands for industrial equipment and industrial systems [25].

China is making significant efforts to push industrial internet platform's construction forward, which has already taken a certain shape and formed a framework. However, its core capacities still lag behind the advanced international capacities. China has over 50 influential industrial Internet platforms, each connected to 5.9×10^4 equipment on average. From the 168 enterprise evaluation data released by Alliance of Industrial Internet, about 83%, 68%, and 54% of these enterprises offer fewer than 20 analytical tools, industrial mechanism models, and microservices, respectively. In China, enterprises in the Internet communication and mechanical manufacturing industries have established a strategic collaboration to integrate online and offline technical benefits in different fields and build a multi-layered development framework [26, 27].

The leading enterprises of the industry will deploy the industrial Internet platform in four major modes as follow: automation enterprises rely on industrial equipment to innovate the service mode; the manufacturing enterprises push forward digital transformation to construct the industrial internet platform; the software enterprises rely on the industrial Internet platform to implement business upgrading and capacity expansion; the information technology enterprises propel the extension of the existing platforms into the manufacturing industry.

4 Development opportunities analysis on the integration of intelligent manufacturing and industrial Internet in China

4.1 Accelerating evolution of the industry chain and dispersion of the dominance right among several key links

Recent years have witnessed the intelligent manufacturing industry's growth and competition intensification in the industrial Internet market. There has been a transition from the conventional industry chain pattern toward new development. Here, the traditional industry chain pattern refers to "the closure of dedicated chips and specialized algorithm knowledge and monopoly by leading manufacturers." On the other hand, the new industry chain pattern refers to a situation where the four components: chips, open-source operating system, algorithms and mechanism models, and data-based novel services are crucial for maintaining the dominant right of the industry in the future. Such transition will, in turn, promote the evolution and upgrade of the entire industrial system.

The conventional industry chain centers on subdivision areas: industrial software, industrial network, industrial control, industrial sensing, and equipment products. The industrial pattern comprises three streams. The industry chain's upstream consists of components and parts of the complete machine/basic technology + operating system + database/embedded system. The midstream consists of full machine/software, while the downstream consists of integration and services.

With the development and IT applications like AI, cloud computing, big data, and edge computing, the emerging industry chain undergoes the transition from the pattern of "industrial software + industrial automation + equipment products" toward "industrial Internet platform + edge computing + intelligent equipment products" (Fig. 2). The emerging industry chain places a greater emphasis on developing the complete machine in the midstream and on IT's extended deployment. The AI chips, FPGA, and CPU constitute the bottom-layer hardware that meets the industrial field's computing demands, which are the crucial and general elements of the emerging industry.

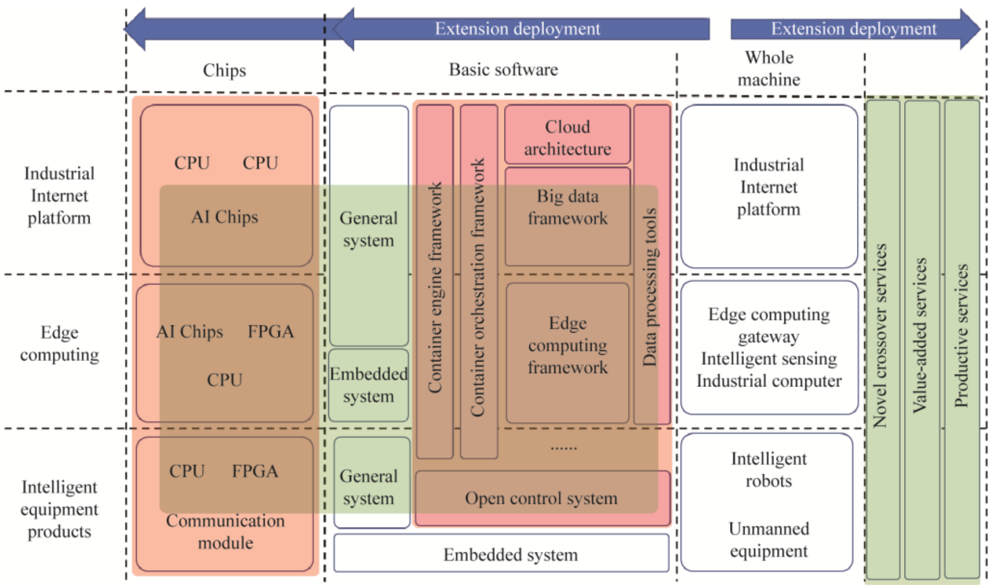

Fig. 2. Pattern and architecture of emerging industry chain composed of the industrial Internet platform, edge computing, and intelligent equipment products.

4.2 Control of the basic software by foreign countries and need for open-source technology

Given the successful development of the basic software sector, open-source has become an important means and helps build basic software. Due to the rapid maturity of the open-source mode, the open-source has found extended applications in intelligent manufacturing and industrial Internet sectors. Three core open-source technologies: containers, microservices, and computing frameworks, have become indispensable for reforming the conventional ecosystem of the basic software and implementing functional decoupling and reintegration.

So far, two core projects including, the container engines and deployment tools, are dominated by foreign companies. The foreign companies or foundations dominate the essential tools and novel architectures for

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microservices, and all of the mainstream computing frameworks are dominated by foreign companies. In the sector of basic industrial software, China still has a long way to elevate the autonomy, controllability, and discourse power concerning open-source technology. China has not yet launched any autonomous programs in the three core open-source technologies— the Chinese enterprises have barely made any progress in this field.

In the future, industrial open-source AI and robots may overthrow the basic software. Emerging IT systems such as AI will become the research hotspots in the sector of the industrial open-source technologies, as AI is anticipated to make breakthroughs and bring new hope for basic software. On the other hand, open-source robots/machine tool control systems are likely to become the cores of control and break the old pattern of the industrial control systems.

4.3 Expectation for creation of a new industry through the use of algorithms and mechanism models and via the deep integration of AI and other new technologies

Algorithms and mechanism models are the achievements of solidification of the industrial knowledge and experience. Industrial expertise was previously used to validate the process simulation process and equipment control to improve the optimization of the industrial production process. Research on the algorithms and industrial mechanisms concentrates on the simulation software and bottom-layer equipment (Fig. 3). Algorithms and mechanism models in process simulation now solidify in products; motion control algorithms in industrial equipment are integrated into the complete machines.

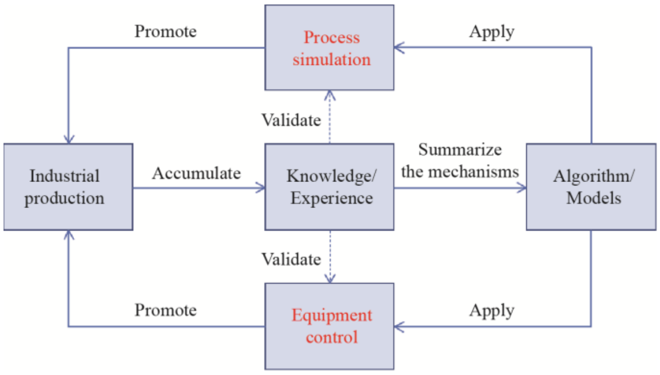

Fig. 3. Relationship between the algorithms of process simulation, mechanism models, and equipment products.

Algorithms and industrial mechanisms are integrated into the complete machines, and they can hardly be decoupled or abstracted. Foreign companies, which are usually owners of the high-end algorithms and mechanism models' intellectual property rights and tightly coupled with their products, impose a technical monopoly. Chinese enterprises can hardly come into contact with the core algorithms and mechanism models. Few are owners of the intellectual property rights of key algorithms. For this reason, China lags behind the foreign countries in R&D, innovation and creation, and talent cultivation in the sectors of core algorithms simulation and control and high-value industrial mechanism models of gas turbines, aircraft engines, and composite materials processing.

The decoupling between algorithms and mechanism models followed by accumulation and deep fusion with new technologies has greatly impacted the emerging industries. The rise of the new data science motivates the data analysis and application in industrial mechanisms. Building an industrial Internet platform will accelerate the accumulation of machine models and data models. AI is the industry’s future focus, while the industrial Internet platform serves as an essential medium. Based on further decoupling of data, mechanisms, knowledge accumulation, and software functions, a large number of third-party developers will significantly accelerate the development and delivery of industrial APPs, thereby promoting rapid iteration and application innovation of the models.

4.4 Emergence of the cross-platform services, value-added services, and productive services

Continuous development of the industrial Internet has inspired rapid progress in cross-platform services, value-added services, productive services, and so on. As the modern service system is being continuously enriched, the advantages of new services have remedied the shortages in conventional services.

Conventional services have a limited profit margin controlled by the upstream links. The traditional automation integration industry has low barriers, and many enterprises compete with each other in the same market and suffer from a low-profit rate. The conventional informationization integration products are less diversified and highly susceptible to control by upstream links. New service modes that exist because of the industrial Internet are driven by data analysis and relying on the industrial Internet platform and big data software as carriers. They have become an indispensable link in the industrial ecology: large-scale equipment enterprises undertake cross-platform deployment in equipment financing and rental and insurance, making the industrial Internet platform the primary service medium. The value-added services oriented toward customers' requirements have been developing rapidly, and household appliances and automobiles are the sectors with significant discoveries. Productive services are giving a growing priority to the supply-demand alignment platform and expert consultation services. They offer aids for the sharing of resources and solutions among industrial manufacturing enterprises.

Along with deepening the research on the industrial Internet, future service models will enrich and strengthen the new service system. This trend will accelerate the digitization and intelligent transformation, upgrade the industrial sector, and promote the significant reform of the conventional industrial ecology.

5 Countermeasures

5.1 Overall strategy

There is a variation in the development trend and importance of different sectors in China's industrial Internet system. Specific measures targeting different sectors of the industrial Internet industrial system shall be implemented including taking great efforts to develop the emerging sectors of the industrial Internet, deploying and planning for the key upstream links of intelligent manufacturing, and catching up with the conventional sectors' development.

By reviewing the subsectors and products of the industrial Internet industrial system, four domains need to be prioritized (Fig. 4) as follows: (1) Sectors monopolized by giants: China has long been weak in the products belonging to these sectors, and discoveries are hardly possible in the relevant technologies and market soon. (2) Sectors of substitution and controllability: China has a certain basis in these sectors, but there is still a long way to catch up with the high-end market and leading international level. (3) Emerging sectors with new opportunities: China keeps pace with the international level in these sectors but never settled the competitive landscape in relevant technologies and markets. These sectors bring China opportunities to grow in the industrial Internet industry, extending to other sectors. (4) Core sectors that involve every competitor: These sectors are related to chips, basic software/open-source, algorithms, and mechanism models, as well as the data-based novel services. They represent the key technologies motivating future industrial development. They are also the shared basis for the intelligentization reform of other sectors.

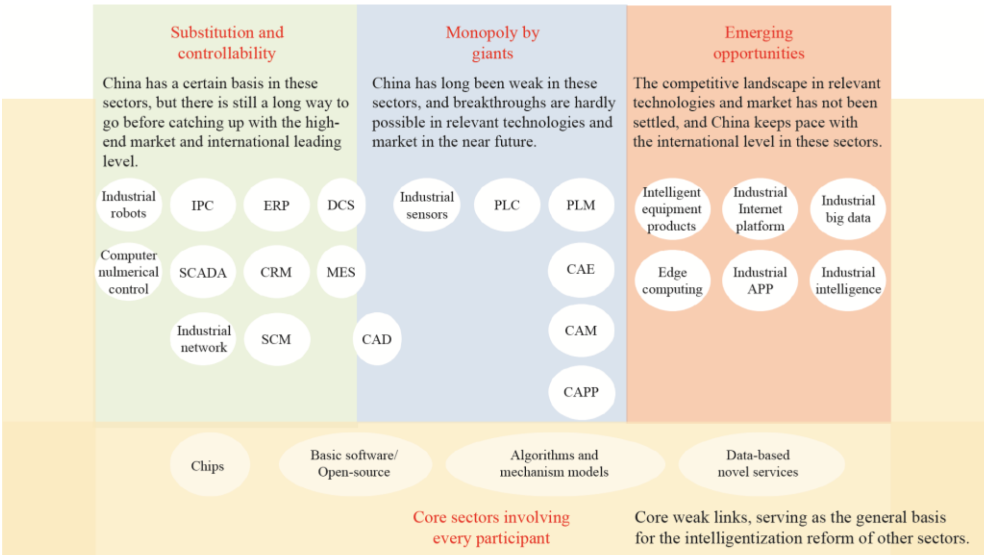

Fig. 4. Sectors covered by the development strategies of the industrial internet.

IPC: industrial PC; ERP: enterprise resource planning; DCS: distributed control system; SCADA: supervisory control and data acquisition; CRM: customer relationship management; MES: manufacturing execution system; SCM: supply chain management;

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CAM: computer-aided manufacturing; CAPP: computer-aided process planning.

5.2 Key directions

5.2.1 Making discoveries in the core sectors of the industrial Internet that involve every competitor

This can be achieved by strengthening the multidisciplinary, multi-sector, cross-platform collaboration approach in technical research and development and application innovation; continuing the accumulation of high-quality codes, high-end algorithms and mechanism models. (1) Chip design oriented toward specific fields such as industrial intelligence should be prioritized, steadily narrowing the gaps in chip manufacturing. (2) The research and development of open-source framework and architecture should be strengthened, the underlying framework and architecture dominated by Chinese enterprises selected and popularized through market screening, the industrial applications of microservices and container technology deepened, and the OT open-source technology deployed on time. (3) The digital models of the key parts of intelligent manufacturing, high-end equipment, and mechanism models of flow industry process should be continuously accumulated and the core algorithms of motion control and simulation should be mastered. (4) The enterprises should be guided to deepen the mining and utilization of industrial data; value-added data businesses centered around products, assets, production, and supply chain should be launched; and the industry–finance combination services should be innovated, such as supply chain finance and financial lease.

5.2.2 Seizing the strategic high ground of the emerging sectors of the industrial Internet

This can be achieved by promoting the integration of conventional products and new technologies, developing solutions oriented toward the following specific industrial scenarios: (1) For intelligent equipment products, accelerating the application of 5G and AI technologies to elevate the human–machine collaboration and intelligent optimization functions of the equipment. (2) Strengthening independent research and development in the open-source technology of the industrial Internet platform; constructing the developer ecology with the leading enterprises as entities; focusing on industrial APP development; and exploring the profit-making business model of the platform. (3) Developing general intelligent industrial algorithms and models that adapt intelligent control and decision-making requirements to offer specific industrial problems solutions. It matches the needs of actual applications of industrial big data and industrial intelligence. (4) Developing edge computing products such as industrial personal computers and intelligent gateway with computing modules suitable for edge computing.

5.2.3 Catching up and replacing in the controllable sectors

This can be achieved by continuously raise the localization rate of the equipment, industrial automation, and industrial software in the key sectors to improve and optimize the performance parameters, stability, and reliability of products. (1) Building domestic industrial robots and numerically controlled machine tools with high stability and high reliability; making efforts to improve the technical parameters of high-end products and expanding the scope of application scenarios. (2) Further increasing the market share of DCS/SCADA in high-end sectors, such as energy and large-scale petrochemistry. (3) For MES, enriching the solutions oriented toward specific sectors and creating several brand products with a competitive edge. (4) Encouraging the enterprises to actively deploy the new industrial network protocols based on services, such as cross-platform solutions, to elevate the sector's discourse power. (5) Enhancing the data analysis and mining and business intelligent decision-making capacities of operation and management software products such as ERP, SCM, and CRM, and offer data value-added service capacities of a higher level.

5.2.4 Catching up in the sectors dominated by giant enterprises

This can be achieved by understanding the subversion and reform of the conventional products and emerging sectors solutions, building up the experimental field to apply self-developed products, improving performance, and narrowing the gaps with foreign products by doing solid research are required as follows: (1) Improving the performance indicators of high-end products of industrial sensors and focusing on the research and development of sensitive materials to achieve substitution and controllability. (2) Studying the influence of open-source and edge computing on PLC products and to deploy subversive technical applications at an early stage. (3) Directing industrial software for research & development and design to PLM, CAD, CAE, CAM, and CAPP, accumulating models and simulation algorithms in the sectors of aerospace, shipping, petrochemistry, and materials, analyzing relevant experience, building up the experimental field for domestic industrial software, and carrying out comparative analysis and research for the applications of domestic and foreign software products.

5.3 Balancing between technological breakthroughs and commercial success

5.3.1 Strengthen the efforts to make technological breakthroughs in the integration of intelligent manufacturing and industrial internet

The technical demands of enterprises include not only the single-node small technological breakthroughs (oriented toward specific scenarios) but also the centralized big technological breakthroughs (oriented toward major sectors and major technologies) (Fig. 5). The former relies on the service institutes/platforms that attempt at the industry–university–research cooperation to build the joint elite technical team from enterprises, institutions of higher learning, and scientific research institutions. The latter should construct the alliance/innovation complex dominated by the leading enterprises to mobilize the efforts to make technological breakthroughs. Common services and training of specialized and novel enterprises can provide support for making technological breakthroughs. Government funding serves as a stimulus, while the enterprise resources can be the entities in implementing this initiative.

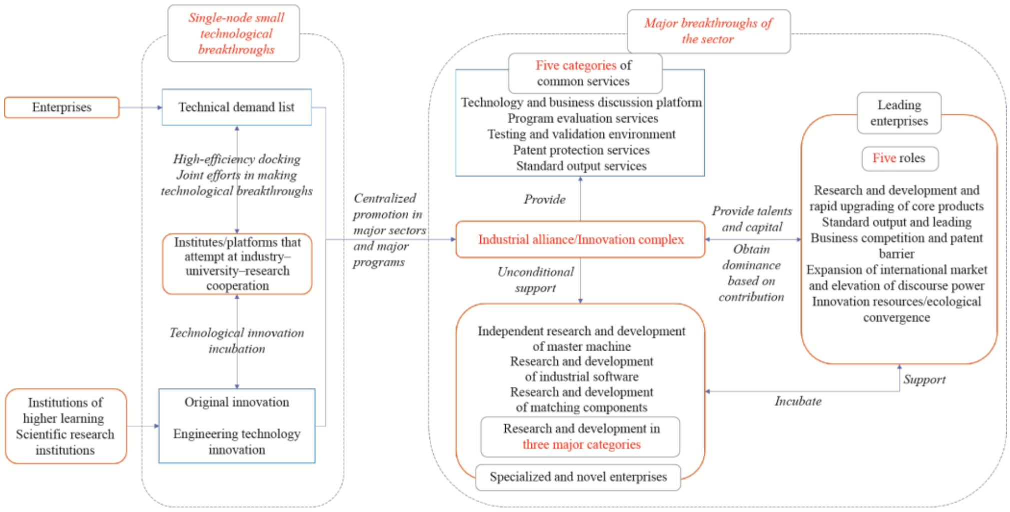

Fig. 5. Diagram of single-node small technological breakthroughs and centralized big technological breakthroughs.

5.3.2 Focus on the commercial success of the integration of intelligent manufacturing and industrial Internet

Based on the common needs of the intelligent manufacturing industry, the experimental field and major equipment (first set) insurance can offer financial support for the application of domestic products after developing the technical solutions. The sustainability of the commercial operations needs to be prioritized, and detailed technical solutions should be created when proposing/bidding for the programs by considering the individualized needs of the small- and medium-sized enterprises. Multidimensional evaluation that includes the business analysis should be conducted. Conditions favorable for market expansion at a low cost should be created for small and medium-sized enterprises using the business promotion platform.

5.4 Strengthening the cultivation of different types of interdisciplinary talents

Higher learning and scientific research institutions should focus on the cultivation of the high-end science and technology innovation personnel. They should cultivate entrepreneurs with strategic technology vision to explore the frontier disciplines/specialties such as AI and industrial big data. They should propose a multidisciplinary training plan and focus on college and enterprise joint training. Entrepreneurs and technical experts can be hired as visiting lecturers, if appropriate, to ensure high-end talent introduction plans being prioritized in the sectors of intelligent manufacturing and industrial internet. The level of recognition regarding the achievements made in industrial mechanism models, algorithms, and industrial APP should be reasonably raised, along with incentives.

Enterprises should attach high importance to the training or introduction of interdisciplinary talents of technology and management in terms of IT and OT. In the meantime, enterprises should step up the cultivation of professionals. Other necessary measures include: exploring for joint cultivation and quality certification of experts; encouraging the job rotation between the departments of informatization and automation; strengthening international study and training of technical staff and supporting the cross-border flow of high-end talents in industry–university–research cooperation; opening up green channels for international collaborations; encouraging the enterprises to build up overseas research centers; and building the talent introduction network. Also, there is a

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need to raise technical workers' literacy, cultivate professionalism in industrial policy design, industrial management, and undertake public services. There is a need to combine with industrial development features and build a professional team of government agencies that meet the demands for public service capacities through collaborations.

References

[1] Zhou J. Digitization and intellectualization for manufacturing industries [J]. China Mechanical Engineering, 2012, 23(20): 2395–2400. Chinese.

[2] Zang J Y, Wang B C, Meng L, et al. Brief analysis on three basic paradigms of intelligent manufacturing [J]. Strategic Study of CAE, 2018, 20(4): 13–18. Chinese.

[3] Alliance of Industrial Internet. Industrial Internet builds the cornerstone of the fourth industrial revolution: Tracking research on the development of international Industrial Internet [J]. China Telecommunication Trade, 2019 (3): 19–23. Chinese.

[4] Wang X W. Future intelligent manufacturing from the perspective of German industry 4.0 strategy [J]. China Informatization, 2014 (15): 8–9. Chinese.

[5] Yan J L, Kong D J. Study on "Industrial Internet" and "Industrie 4.0" [J]. Strategic Study of CAE, 2015, 17(7): 141–144. Chinese.

[6] Zhou J. Move towards a new generation of intelligent manufacturing [J]. Science & Technology Industry of China, 2018 (6): 20–23. Chinese.

[7] Zhou J. Intelligent mannfacturing: Main direction of "Made in China 2025" [J]. China Mechanical Engineering, 2015, 26(17): 2273–2284. Chinese.

[8] Chen Z X. Industrial Internet is the kernel of intelligent manufacturing [J]. China Informatization, 2016 (1): 7–8. Chinese.

[9] Zhu J Y. Significance, technologies and implementation of intelligent manufacturing [J]. Machine Building & Automation, 2013, 42(3): 1–6, 10. Chinese.

[10] Dong J. Yu Xiaohui: Promote the construction of Industrial Internet to empower the transformation and upgrading of manufacturing industry [J]. Automation Panorama, 2019 (4): 22–25. Chinese.

[11] Chen Y. Application of Industrial Internet in intelligent manufacturing [J]. Information Technology & Standardization, 2017 (8): 25–27. Chinese.

[12] Xiao R M, Huo P. Promoting the modernization of industrial chain in manufacturing industry with Industrial Internet as the key [J]. Journal of Changsha University, 2020, 34(1): 83–89. Chinese.

[13] Liu L. Development of industrial robot remote monitoring diagnostic services system [D]. Dalian: Dalian University of Technology(Master's thesis), 2014. Chinese.

[14] Zhao S Y. The study of remote monitoring and fault diagnosing system for manipulators [D]. Dalian: Dalian University of Technology(Master's thesis), 2016. Chinese.

[15] Lee J, Bagheri B. Cyber-physical systems in future maintenance [C]. Pretoria: The 9th World Congress on Engineering Asset Management, 2014.

[16] Zhang G N, Jiang X H. How Chinese companies keep up with the international footsteps in the field of industrial control: Current situation and development suggestions of industrial control system industry [J]. Industrial Design, 2016 (5): 162–163. Chinese.

[17] Yu Y, Yu J, Jing B. The development of high temperature pressure sensor [J]. Science and Technology & Innovation, 2015 (17): 42, 45. Chinese.

[18] Marsi N, Majlis B Y, Hamzah A A, et al. Development of high temperature resistant of 500 °C employing silicon carbide (3C-SiC) based MEMS pressure sensor [J]. Microsystem Technologies, 2015, 21(2): 319–330.

[19] Lu C, Huang M G, Li X, et al. Research on temperature compensation of silicon on sapphire pressure sensor [J]. Measurement & Control Technology, 2017, 36(4): 113–116. Chinese.

[20] Jiang X H, Zhang G N. Industrial software industry status quo, development trend and basic analysis [J]. World Telecommunications, 2016 (2): 13–18. Chinese.

[21] Wang Y H. Development status and trend of Chinese industrial software [J]. China Industry Review, 2018 (2): 58–63. Chinese.

[22] Zhou J. Development status of Chinese industrial software enterprises and breakthrough of bottleneck gradient [J]. China Industry and Information Technology, 2020 (3): 56–61. Chinese.

[23] Wang J W. Integration and innovation between Internet and industry [J]. China Informatization, 2014 (9): 31–34. Chinese.

[24] Guo Z H. Analysis of current situation and trend on Industrial Internet technology [J]. Process Automation Instrumentation, 2020, 41(5): 1–4, 8. Chinese.

[25] Zhao M. Six supporting elements of Industrial Internet platform: Interpretation of *Industrial Internet platform white paper* [J]. China Mechanical Engineering, 2018, 29(8): 1000–1007. Chinese.

[26] Lv W J, Chen J, Liu J. I Intelligent manufacturing and firm-level platform building in Industrial Internet: A case study of Haier [J]. China Soft Science, 2019 (7): 1–13. Chinese.

[27] Zhuang C B, Liu J H, Sui X F, et al. Status, technical architecture and application challenges for transformation and updating of discrete manufacturing industry driven by Industrial Internet [J]. Computer Integrated Manufacturing System, 2019, 25(12): 3061–3069. Chinese.