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Intelligent Manufacturing Enabled by Information and Communication Technology in Industrial Environment

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Abstract: Next-generation intelligent manufacturing systems are being developed to integrate information and communication technologies (ICTs) with industrial technologies and to support a rapidly unfolding new cycle of industrial revolution. The rapid evolution of ICTs has shown potential to accelerate the development of intelligent manufacturing. In this study, we propose a technical framework for the emerging intelligent manufacturing system and elaborate the connotations and characteristics of an architecture of technical subsystems regarding ICTs from the perspective of industrial Internet systems and four basic technologies, including industrial big data, artificial intelligence (AI), fifth-generation mobile communications (5G), and modeling simulations and digital twin technology. Subsequently, we present vertical, horizontal, and end-to-end application scenarios of intelligent manufacturing enabled by ICTs, and present several suggestions for the promotion of the new intelligent manufacturing system through ICTs. First, special science and technology projects should be established that focus on advanced networks, collaborative computing, and reasoning systems using industrial knowledge. Second, industrial development should focus on implementing 5G applications, network collaboration, and intelligent and intelligently connected products based on next-generation AI technology, as well as domestic development of modeling simulations and digital twin tool sets and systems. Third, application demonstrations should be conducted regarding industrial design based on 5G Plus industrial virtual reality, industrial platforms for AI using the Internet of Things, and intelligent design of industrial products based on modeling simulation and digital twin technology. Meanwhile, efficient and collaborative working mechanisms should be developed to promote new intelligent manufacturing policies, accelerate the construction of interconnection standards groups, promote industrial logistical networks and supply chains through academic-industrial research collaboration, and enhance the deep integration of industry and education in intelligent manufacturing.
Keywords: information and communication; intelligent manufacturing; enabling technology; digital twin

1 Introduction

A new round of industrial revolution has been rapidly developing on a global basis, driven primarily by dramatic advancements in scientific and technological as well as industrial fields. China is entering an era that may be described as Intelligent Plus, in which it faces complex new international and domestic situations and a new

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path forward. China will build a new development dynamic based on "a domestic cycle as the main body, along with a mutually reinforcing domestic and international double cycle," in accordance with the new development philosophy of "innovation, coordination, green development, openness, and sharing" [1]. The manufacturing industry is the main body of the national economy, and its development should be adapted to match the new era with its evolving situations and new journey. At present, China's manufacturing industry is entering a stage of high-quality development and is in a critical period of digital transformation and intelligent upgrades. As the main direction of high-quality development of the manufacturing industry, intelligent manufacturing is of great significance to the objectives of accelerating the development of a modern industrial system, consolidating and strengthening the foundation of the real economy, establishing a new development pattern, and building a digital China.

Since the 13th Five-Year Plan period, the state has actively promoted pilot demonstrations of applications of intelligent manufacturing and the establishment of systems of standards for intelligent manufacturing, which has significantly improved the level of digitalization, networking, and intelligence of China's manufacturing. These changes have mainly been evident in terms of the following factors. (1) The status of a manufacturing power is further consolidated, the scale of the manufacturing industry has ranked first in the world for many years, and a number of high-end brands have entered global distribution. (2) Major breakthroughs have been achieved in innovation in key areas, such as the leap-forward development of major equipment manufacturing capabilities, and the smooth implementation of major projects in the aerospace field. (3) The process of upgrading the industrial framework has been accelerated, and the leading role of the high-tech manufacturing and equipment manufacturing industries has been significantly enhanced. For example, the digital transformation of the manufacturing industry has been comprehensively accelerated, and advanced manufacturing clusters have been established in many fields. (4) The strength of manufacturing enterprises has been significantly enhanced, their level of specialization has been continuously improved. Meanwhile, the role of enterprises in innovation has been significantly enhanced, a number of strong, well-developed leading enterprises have been cultivated, while more than 100 industrial Internet platforms with certain industry and regional influence have been established. (5) The information and communication industry has achieved a new leap forward. New technologies such as fifth-generation mobile communications (5G) and the industrial Internet are being rapidly integrated in the manufacturing industry. New scenarios, new models, and new forms of business such as digital factories are flourishing. The industrial Internet platform helps to establish networked collaboration platforms and intelligent production systems, as well as adaptive extension of existing services, digital management, and other new intelligent manufacturing models.

In this new era and evolving situation, new concept for intelligent manufacturing system [2–4] has been developed. This evolution has been driven by a new generation of artificial intelligence (AI) technology, which contains new manufacturing product, capabilities, and resource systems, as well as new networks and perception systems, and new platforms, standards, security systems, applications, and user systems, along with other complex systems. It should be noted that the construction of a new intelligent manufacturing system is not a simple problem of technical transformation, but rather one of a strategic system engineering, which requires the establishment and operation of an innovative pattern of "integrating technology, industry, application, talent, policy, and security systems" [5,6]. The enabling technologies are becoming an important support for the digital transformation and intelligent upgrades towards the new intelligent manufacturing system. The technologies enabling intelligent manufacturing are an important part of the group of technologies required to realize the new intelligent manufacturing system, which mainly include new manufacturing science and technology, new information communication technology, new intelligent science technology, and new technologies for applications in the manufacturing field.

This study focuses on the information and communication technologies enabling intelligent manufacturing in the industrial environment. In particular, we focus on the critical technologies enabling the future development of intelligent manufacturing. We limit our exploration to some typical information and communication technologies, such as 5G, industrial big data, industrial Internet systems, AI, modeling and simulation and digital twin technology, along with some categories. Within this scope, we elucidate and analyze the connotations and development trends of technologies enabling information and communications in the industrial environment, and summarize and refine the typical vertical, horizontal, and end-to-end application scenarios for information and communication technologies enabling intelligent manufacturing. We then propose some scientific and technological projects, as well as industrial developments, application demonstrations, and so forth to provide a

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basic reference for in-depth research on the emerging new intelligent manufacturing system.

2 Technical system of the new intelligent manufacturing system

In the new intelligent manufacturing system, a new manufacturing product, capacity, and resource system will provide products, capabilities, and resources that are shared and served across the entire manufacturing system and lifecycle activities. New networks or perception systems will realize ubiquitous deep interconnection and perception across the entire industrial system, the entire industrial chain, and the entire value chain. The new platform system will be designed as a core carrier providing industrial cyber–physical integration and intelligent services, and realize virtualization and servitization of manufacturing products, capabilities, resources, access networks, and perception systems. The new standards security system will guarantee safe and credible industrial resources, capabilities, and products integration optimization as well as system-wide applications. Similarly, the new application system will provide a variety of industrial applications for different industries, fields, and scenarios, and the new user system will be based on a person/organization model composed of service providers, service operators, and service users.

The new intelligent manufacturing system may be described in terms of six notable new characteristics. (1) New technologies relying on digital, networked, cloud-based, and intelligent technologies and new methods will constitute a user-centered, unified operation, and a new intelligent manufacturing service cloud (network) that covers resources, products, and capabilities. Users will be able to obtain new intelligent manufacturing resource services, product services, and capability services on demand through new intelligent terminals and intelligent manufacturing service platforms to complete various activities of the manufacturing lifecycle with high quality and efficiency. (2) The new model of collaborative, interconnected, and intelligent manufacturing centered on governmental, enterprise, and individual users will optimize and integrate people, machines, things, environments, and information, and support the development priorities of digitalization, materialization, service transformations (cloudization), collaboration, customization, flexibility, and green and intelligent development. (3) The new business format is reflected in ubiquitous intelligent connections, intelligent leadership, data- and model- driven methods, shared services, cross-border integration, and innovation. (4) New features for people, machines, things, environments, and information in the whole system and lifecycle activities (industrial chain) of new manufacturing will be designed to autonomously and intelligently carry out perception, interconnection, collaboration, learning, analysis, cognition, decision-making, and control, and to perform other activities. (5) The new content will promote the further integration and optimization of people, technology and equipment, management, data, materials, capital and other elements in the entire manufacturing system and lifecycle activities along with the flow of people, technology, management, data, materials, and capital. (6) In this emerging industrial transformation, supporting the digital transformation and intelligent upgrading of the new intelligent manufacturing system, realizing high efficiency and quality along with economical and green development and flexible manufacturing of products and user services, and improving the market competitiveness of enterprises are critical new goals.

The proposed architecture of the new intelligent manufacturing system is suitable for vertical scope, horizontal scope (the whole industry chain), and end-to-end integration and optimization. While reflecting the main characteristics of the new system, it highlights systematic innovations such as the new architecture of edge/cloud/terminal collaboration, as well as the deep integration of new information and communication technologies and manufacturing technologies, the virtualization and servitization of perception, access, and communication networks, industrial mechanisms model-driven, and cloud-native industrial application development environments. The corresponding technology system (Fig. 1) will be led by a new generation of AI technology and may be further divided into subsystems such as overall architecture, enabling technologies, security technologies, standards, and industrial software.

3 Information and communication enabling technology subsystem

The subsystem of information and communication enabling technologies is the core support content of the new intelligent manufacturing system, and will play a key role in the construction and application of the system. Therefore, the present work paper focuses on presenting and organizing the typical information and communication enabling technology system in terms of 5 categories and 13 technological sub-directions to support the new intelligent manufacturing system to serve the digital transformation and intelligent upgrade process of the manufacturing industry. Among these technologies, the industrial Internet system is the core component in terms of subdivision granularity, while 5G, industrial big data, AI, and modeling simulations and digital twin technologies may be categorized as part of the cross-domain integration of native technologies.

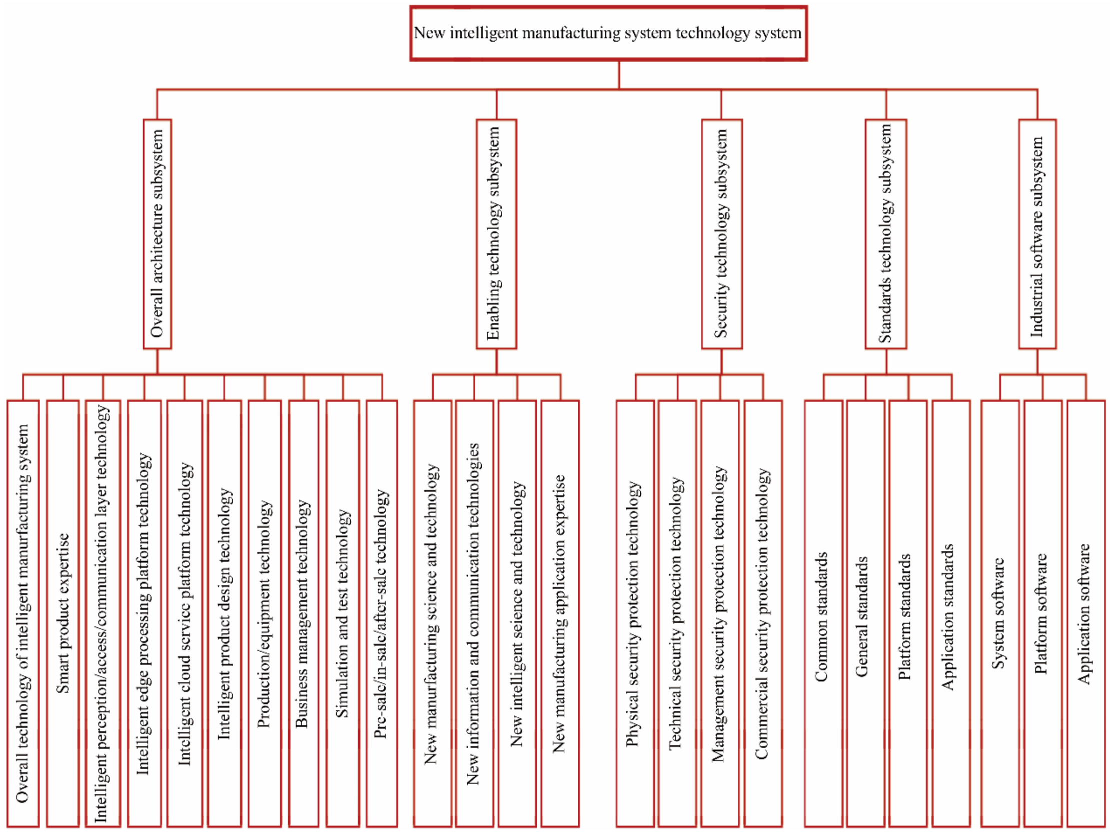

Fig. 1. Block diagram of the technical architecture of the new intelligent manufacturing system

3.1 Industrial Internet systems: a core class of technologies

3.1.1 Industrial Internet technology

The industrial Internet is a new type of infrastructure that deeply integrates new information and communication technologies with the industrial economy and provides a new application model and industrial ecology. It comprehensively connects people, machines, things, and systems, and establishes a manufacturing and service system covering the entire industry chain and value chain. It realizes the circulation and interaction of data, hardware, software, and intelligence, as well as industrial digitization, networking, and intelligence [7]. The industrial Internet is based on computer networks; the platform provides the center of the architecture, while data is transmitted around the system as its key element, and the overall system should be designed so as to guarantee the security of all operations. It has the characteristics of ubiquitous connectivity, cloud service, knowledge transformation, and application innovation [8]. New technologies represented by microservices and containerization, cloud middleware, low-code development, and new platform architectures, will be integrated into and drive the new development of the industrial Internet to provide support for a series of key required capabilities, such as massive industrial data and the management of various industrial models, as well as industrial modeling analysis and intelligent decision-making, agile development and innovation in industrial applications, and industrial resource aggregation and optimal allocation.

3.1.2 Internet of Things (IoT) and cyber–physical system technology

Through radio frequency identification, infrared induction, global positioning, laser scanning, and other information sensing equipment, any item may be connected to the Internet. Information exchange and communication can then be carried out according to an agreed protocol to realize intelligent identification, positioning, tracking, monitoring, and management over an IoT network. The IoT is characterized by large-scale and comprehensive perception, reliable transmission, and real-time intelligent processing, and has been designed to develop in the direction of intelligent connection of a wide variety of basic devices, with a focus on security and

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privacy, green low-power or passive devices [9].

Cyber-physical system (CPS) technology describes a closed-loop system enabling an automatic data flow between an information space and a physical space, covering state perception, real-time analysis, scientific decision-making, and precise execution of control functions. CPS involves the core aspects of data-driven and software-defined methodologies, as well as ubiquitous connectivity, virtual-real mapping, heterogeneous integration, and system autonomy [10,11]. These characteristics are expected to improve the implementation capability, adaptability, scalability, elasticity, security, and availability of such systems over time. In the future, as a technical support, CPS will be integrated with the industrial Internet and digital transformation to promote development in a more systematic and complex direction, and to enhance capabilities such as autonomous cognition and learning, control, decision-making, as well as real-time feedback to precise execution of physical spaces.

3.1.3 Cloud computing technology

Cloud computing technology organizes and flexibly calls various information resources over a network to realize information processing via large-scale computing. It uses distributed computing and virtual network resource management technologies to aggregate computing resources into a shared pool to provide services to users in a dynamic, on-demand, and measurable way [12]. The basic characteristics of cloud-computing technology include on-demand self-service, broadband network access, resource pooling, fast elasticity, and measurable services [13]. It is further integrated with basic capabilities such as databases, algorithm libraries, model libraries, big data platforms, computing capabilities, and so forth, and focuses on responding to the needs of industrial intelligent manufacturing and providing targeted services in many aspects, such as cloud demonstration, design, simulation, production and processing, experimentation (testing), management, maintenance, and integration.

3.1.4 Edge computing technology

In the field of industrial Internet intelligent manufacturing, edge computing provides intelligent services at the edge of the network, near the primary source of communication links and data, to meet the key requirements of industry digitization such as agile connections, real-time operations, data optimization, application intelligence, security, and privacy protection [14]. Low latency, high bandwidth, high security, distribution, and location awareness are the main features of edge computing technology. The future development of edge computing technology may be expected to depend on the evolution and development of resource allocation management technologies to promote various manufacturing resources, products, and capabilities to play a better role in the deployment of edge management systems, and heterogeneous technological integration must be further strengthened to consider virtualization, service, on-demand combinations, and the integration of heterogeneous manufacturing resources and capabilities, as well as the integration of heterogeneous models and virtual prototypes.

3.1.5 High-performance computing technology

High-performance computing technology refers to the use of computing systems and environments on many processors or clusters to process large-scale data-intensive computing tasks, which can be divided into, e.g., simulation, modeling, and rendering tasks. The relevant system comprises four parts, including computing, storage, network, and cluster software. Parallelism, high bandwidth, large-capacity storage, and scalability are the basic characteristics of high-performance computing technology. The future development of high-performance computing technology is expected to focus on deepening the basic theory as well as developing algorithms conducting research on systems, such as embedded high-performance computing hardware, high-performance computing cluster management systems, operating systems, and high-performance storage systems, alongside deep integration of various technologies such as information communications, AI, systems engineering, and manufacturing, with a broad development space. Based on new technologies such as cross-media reasoning, these developments will contribute to research on user-oriented intelligent cloud service technology, and are expected to be combined with cloud services to expand the scope of their application. To facilitate this work, research on new modes, processes and means over the entire manufacturing lifecycle should be considered, such as CPS technology based on high-performance simulation.

3.1.6 Blockchain technology

Blockchain technology automatically executes smart contracts without the need for review by a centralized agency. It can achieve consistent data storage, is difficult to tamper with, and can prevent erroneous denials and incorrect operations of other accounting functions. It integrates a point-to-point network, cryptography, consensus mechanism, smart contracts, and other technologies, provides a trusted channel for information and value transfer and exchange in an untrusted network [15], an is characterized by decentralization, tamperproof design, traceability, and transparency to participants [16]. The continuous integration of blockchain technology and other technologies has driven the development of more secure and efficient technological applications, including integration with AI technology to solve the problems of data and model reliability in AI applications and reduce the risk of cyberattacks against AI applications. The integration of blockchain systems with big data technology is expected to enhance the reliability and traceability of data storage, connect scattered data islands, and enable sharing of data and data mining on a larger scale. Integration with the industrial Internet is expected to support the network and physical security of industrial Internet, construct trusted data networks, and lead to new application scenarios such as distributed intelligence. These technologies are also expected to promote global interoperability and mutual recognition of industrial Internet identification and facilitate the process of data marketization and the emergence of an industrial ecology based on an Internet of all things.

3.1.7 System security technology

System security refers to the application of system security engineering and system security management methods to identify hidden risks and take preventive measures to improve the performance, progress, and cost of various levels of security in the system lifecycle. The main features include: limited access to resources of massive and heterogeneous industrial equipment; coordinated operation and maintenance as well as rapid deployment of industrial clouds with different architectures; industrial microservice diversification and multi-service collaborations; collaborative work and open customization of industrial applications; and multi-source heterogeneous, large-scale access, and sharing of industrial data. In the future, the development of industrial Internet and intelligent manufacturing will accelerate, massive industrial equipment will be further incorporated into ubiquitous interconnection, and system security technologies will focus on application breakthroughs in technical directions such as industrial control honeypots, data protection, supply chains, and AI security, and lead the development and implementation of better industrial security practices.

3.1.8 Automatic control technology

Automatic control technology drives automatic control devices, which regulate the automatic operation of controlled objects such as production processes or machinery according to a given set of rules (targets), causing the physical quantities and processing technology of the controlled object to vary its operation according to predetermined requirements. Programmable logic controllers (PLCs) and industrial computers have played a key role in this process. Miniaturization, networking, and improving communication performance are key aspects of the future development of PLCs. Along these lines, distributed control systems (DCSs) are developing toward integrated measurement, control, and management, and are steadily improving in terms of miniaturization and communication.

3.1.9 Sensor technology

Sensor devices are designed to sense variation in a specified physical quantity and convert the information into an output signal according to a given mathematical relationship, which is the primary link to realize automatic detection, automatic control, intelligent control, etc. The main features of emerging sensor technology include miniaturization, digitization, multi-functionality, systemization, networking, and intelligence. In the future, sensor technology for intelligent manufacturing empowerment is expected to develop along the lines of ubiquitous distributed computing. In practice, this may be expected to include the application of new materials and new processes to develop new sensors to achieve multi- functionality, high-precision, integration, and intelligence, to promote the miniaturization of sensing technology hardware systems and components, and to realize wireless networking through cross-integration of sensors with other types of devices.

3.2 Four basic technologies

3.2.1 Industrial big data technology

Industrial big data refers to the data, technology and applications generated in all aspects of the product lifecycle in a typical intelligent manufacturing model in the industrial field. Big data and associated computational processing in the industrial environment not only exhibits the 4V characteristics of big data [17], but also involves

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the comprehensive integration of multi-source data, complex heterogeneous data types, time series correlation, highly real-time operational requirements, and high uncertainty. In the design process, data-driven industrial design and modeling and simulation will be widely used in non-mechanical modeling of complex products; in the production process, data-driven production process control will promote the application of data-based fuzzy control to adapt more ably to the emerging complex industrial environment with its characteristics of strong noise and uncertainty. In operational and maintenance processes, the data-driven equipment health management model will further improve the equipment mechanism model and improve the timeliness and accuracy of equipment operation and maintenance.

3.2.2 AI technology

The new generation of AI refers to AI based on new information environments, technologies, and development goals. This development trend includes data-driven deep reinforcement learning intelligence, network-based swarm intelligence, technology-oriented hybrid intelligence based on human–computer/brain–computer interaction, cross-media reasoning intelligence, and autonomous intelligent unmanned system. The new generation of AI technology has gradually become a general-purpose technology, which is expected to penetrate the field of intelligent manufacturing toward widespread implementations, and to promote transformation and upgrades in product design, production control, and manufacturing services toward digitalization, networking, cloudification and intelligence.

3.2.3 5G technology

As a new generation of broadband mobile communication technology with high speed, low latency, and large connection, 5G network infrastructure realizes the massive interconnection of people, machines, and things. 5G meets the requirements of end-to-end millisecond-level delay and nearly 100% reliable communication, and provides a technical infrastructure to support real-time control and reliable early warning systems in new intelligent manufacturing systems. In the future, 5G is expected to create business value in scenarios such as remote control and predictive equipment maintenance. Industrial virtual reality (VR) will assist industrial design and realize 3D virtual displays of factories, which may be expected to improve operations management and facilitate enhanced control of production process flow. 5G will empower industrial augmented reality (AR) and industrial VR in the two aspects of improving the performance of industrial AR/VR displays and enhancing the interactivity of industrial AR/VR experiences.

3.2.4 Modeling, simulation, and digital twin technology

Modeling, simulation, and digital twin technology deeply integrates information and communication technology, AI technology, modern modeling and simulation, and manufacturing expertise, aiming to improve the comprehensive performance of system modeling, simulation operation, result analysis and processing, and so forth These technologies can construct, and map physical objects upon receiving sensor data, and then predict their evolution over time. These techniques will require the evaluation and management of corresponding digital models, and they are expected to enable production engineers and facility operations management to conduct real-time or quasi-real-time monitoring, diagnosis, prediction, and decision-making based on simulation methods, and to optimize the full lifecycle of many physical objects involved in the production process flow via automatic or semi-automatic feedback or counter-control. The main aspects of future development are expected to include advancing the state of research on new modeling and simulation technologies (such as model engineering, data-driven modeling and simulation, high-performance simulation, VR/AR engineering, cloud simulation, edge simulation, embedded/pervasive simulation, intelligent simulation, complex system simulation, and reality emulation) and constructing new modeling methods and simulation models and associated technical means.

4 Application scenarios of information and communication technologies empowering intelligent manufacturing

Based on the application practice of information communication enabling technology, the present work summarizes and forms three kinds of application scenarios of the new intelligent manufacturing system, including vertical, horizontal, and end-to-end applications (Fig. 2). (1) The scope of vertical applications may be primarily classified according to the level of equipment, workshops, enterprises, and industries/regions, to realize the integrated application between different levels and various systems, to enable the seamless connection of people, information, and physical systems in all links inside and outside the enterprise. (2) The horizontal application of the new intelligent manufacturing system mainly considers the entire manufacturing industry chain according to R&D design, production and manufacturing, operation management, process and supply chain control, simulation and testing, and services, realizes the circulation, integration and fusion of data across the entire product lifecycle, and drives information sharing, resource integration, process optimization, and social collaboration in different manufacturing links. (3) End-to-end applications for the new intelligent manufacturing system mainly involve the connection of multi-source heterogeneous information on information terminals and digital and physical terminals, focusing on products and services from the supply end to the user end, covering all aspects of the product lifecycle and each terminal, realizing the integration and interoperability of manufacturing resources, products, and capabilities based on industrial Internet platforms.

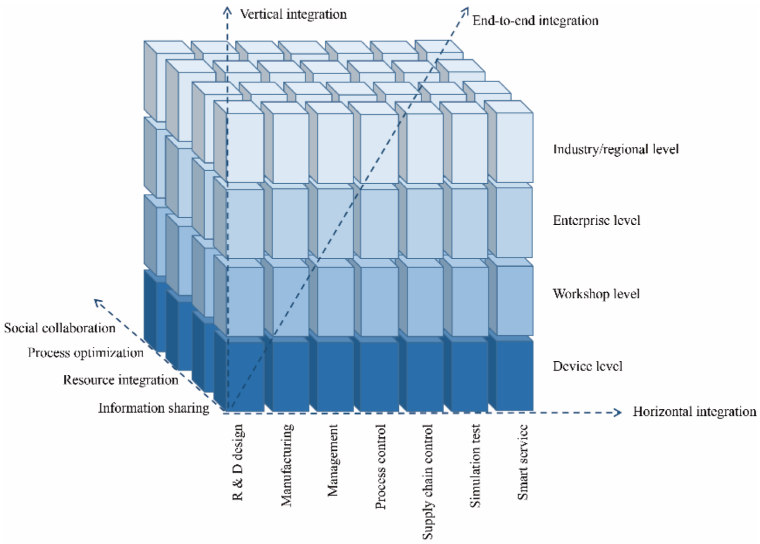

Fig. 2. Schematic diagram of application scenarios of information and communication enabling technologies enabling intelligent manufacturing.

4.1 Vertical application scenarios of industrial internet system technology empowering intelligent manufacturing

4.1.1 Sensor technology enables intelligent manufacturing

Sensor technology can enable industrial equipment control. For example, temperature sensors on CNC machine tools are used to detect temperature differences caused by motor rotation, component movement, cutting, etc. during processing, and to provide input conditions to facilitate the implementation of temperature compensation. Sensor technology enables process optimization. For example, photoelectric strip deviation detectors are used to detect the size and direction of strip materials that deviate from the correct position during processing to provide key signals for deviation correction control circuits in the production process of printing and dyeing, paper feeding, film, and magnetic tape. Sensor technology enables equipment health monitoring, such as the monitoring of tool wear by Hall sensors, which can finely sense the load, current, voltage changes, and subsequent power changes of machine tool spindle motors caused by tool wear, and provide timely alarms for the CNC system.

4.1.2 Automatic control technology enables intelligent manufacturing

PLC control systems are the primary framework used in most industries, which can provide a safe and reliable control scheme for multiple pieces automation equipment. The DCS control system is the second most common; DCS is a distributed computer control system based on microprocessors, which incorporates decentralized control functions, centralized display operations, and considers the principles of autonomous and comprehensive coordination design, which is also a product of the combination of control technology, computer technology, communication technology, and graphic display. Industrial computer control systems are third most important platform. As a basic and distributed industrial automation control, there is a tendency to replace PLC and DCS control systems. Driven by industrial Ethernet and advanced control theory, the application of automatic control technology in the field of intelligent manufacturing is expanding and development is extending toward field bus control systems.

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4.1.3 IoT/CPS technology enables intelligent manufacturing

The IoT technology may be considered in regard to two principle factors, namely industrial production in an industrial IoT environment, which can collect and mine a large amount of data from industrial production sites to determine process shortcomings so as to optimize production processes in a targeted manner, and real-time monitoring and analysis of the procurement, sales, inventory, etc. of raw materials involved in industrial production, as well as finished products, based on IoT technology, to facilitate the optimization of enterprise supply chain management. Industrial environment protection equipment should be connected to the industrial IoT, and should be used to monitor and analyze the key indicators of the pollution control links in real time to provide a basis for enterprise-level production energy consumption and environmental protection management. These systems are expected to be utilized to collect personnel and equipment data on procurement, production, sales, after-sales, and other links to provide data support for precise decision-making at the enterprises level based on the industrial IoT.

The application of CPS technology involves various manufacturing scenarios such as equipment management, flexible production, quality control, operation and maintenance, and supply chain collaboration. Manufacturing enterprises rely on the platform to code, componentize, and model knowledge of common technologies such as industry principles, basic processes, business processes, and expert experience, and to accumulate and share them on demand in the form of digital models. In the high-end equipment manufacturing industry, typical scenarios include model-based design and development, AI decision-making for complex problems in the production process, and fault prediction and health management for industrial equipment.

4.1.4 Industrial internet technology enables intelligent manufacturing

In terms of collaborative manufacturing, manufacturing enterprises use the bilateral connection of the Internet platform to break down industry barriers and information asymmetries, and to realize the rationalization and efficient matching of the supply and demand of idle equipment, technology, and talents in the manufacturing industry. In terms of personalized customization, based on the industrial Internet platform, enterprises are expected to accelerate the transformation of fragmented and popular demand information into standardized and executable process language, and to drive R&D, production, operations, maintenance, and other departments to coordinate and allocate manufacturing resources to respond quickly to users' individual needs. Moreover, the emerging technological transformation envisions that they will carry out intelligent marketing, interactive design, visual production, and precise services to achieve an all-round and full-lifecycle precise connection between manufacturing resources and user needs. In terms of supply chain optimization, enterprises will rely on the industrial Internet platform to integrate upstream and downstream resources, and to establish a coordinated operations system for logistics, information flow, and capital flow. These methodologies will enable enterprise to provide customer-oriented inventory management, parts management, real-time replenishment, logistics and distribution services and to respond to customer delivery needs in real time. In terms of remote operation and maintenance services, enterprises will rely on the industrial Internet platform to collect data across the entire lifecycle of products, analyze operation and maintenance requirements, customize service processes, and dynamically allocate personnel and equipment to achieve interdepartmental and enterprise-wide scheduling and coordination of service capabilities.

4.1.5 Cloud computing technology enables intelligent manufacturing

Cloud-based manufacturing of entire systems across their business lifecycles is expected to realize data interoperability, information sharing, and process collaboration through cloud computing, and to facilitate the use of the large-scale processing capabilities of cloud computing centers to implement machine learning, analysis, cognition, and decision-making systems to support business optimization. With the help of cloud computing, sharing and collaboration can be realized in a broad sense, including (1) intelligent "soft" manufacturing resources involving various models, (big) data, software, information, and knowledge in the manufacturing process; (2) intelligent "hard" manufacturing resources, namely intelligent manufacturing facilities, materials, and energy systems involved in the whole lifecycle of manufacturing, such as machine tools, robots, machining centers, computing equipment, simulation equipment, experimental equipment, measurement equipment, and metering equipment; (3) intelligent manufacturing capabilities such as manufacturing process-related demonstrations, designs, simulation, production, experiments and testing, management, sales, (product) operation, (product) maintenance, and integration; and (4) intelligent manufacturing of interconnected products, including digital, networked, and intelligent new interconnected manufacturing products, such as intelligent transportation vehicles and construction machinery accessed through new Internet networks.

4.1.6 Edge computing technology enables intelligent manufacturing

The Edge and cloud computing paradigms are expected to work together to process computational tasks in the industrial cloud environment, which will create a new mode of data analysis and computing that integrates cloud and network edge sides. However, existing cloud computing models are largely unsuitable for the complex task of analyzing the massive data involved in industrial production processes in real time. To address this problem, intelligent service may be provided at the network edge, as mobile devices are generally closer to the relevant object and data sources. This flexible approach can meet the needs of industrial manufacturing for agile connection, real-time business, data optimization, and application intelligence, as well as security and privacy protection.

4.1.7 High-performance computing technology enables intelligent manufacturing

High-performance computing will be combined with emerging technologies such as cloud computing, IoT, big data, and simulation to construct high-performance cloud platforms, virtualize and serve high-performance resources, and form a high-performance service cloud pool for coordinated and optimized management and operation. High-performance computing technology obtains high-performance computing resources and services in a timely manner through networks and terminals to meet various high-performance computing needs in industrial manufacturing, such as modeling, simulation, and massive data processing.

4.1.8 Blockchain technology enables intelligent manufacturing

Supply chain visualization, distributed production, industrial logistics and transportation management, and industrial maintenance work order management are typical application scenarios. Blockchain technology can also provide security guarantees around the supply chain finance of industrial enterprises, leasing of industrial equipment products, second-hand trading of industrial products and equipment, and industrial product recycling. Intelligent manufacturing data platforms built on the basis of blockchain technology comprise decentralized data platforms, which are designed to be trusted and safe owing to the distributed nature of blockchain ledger systems. These technologies enable the construction of decentralized data platforms that link design, production, logistics, and other links between manufacturing enterprises and their upstream and downstream enterprises, and will allow organizations to avoid the phenomenon of “data islands” between enterprises. This will support the establishment of good data collaboration between factories and enterprises, and enable the manufacturing industry to share data safely across platforms.

4.1.9 System security technology enables intelligent manufacturing

At present, related applications are being developed together by multiple parties, including industrial enterprises as well as platform, security, Internet, and hardware companies.

(1) Leading industrial enterprises and large-scale intelligent manufacturing companies are expected to construct industrial Internet platforms and simultaneously implement security reinforcement to meet the needs of industrial transformation and development. From the perspective of comprehensive security protection, corresponding security protection measures should be deployed at all levels of platforms and data. (2) Large manufacturing enterprises and Internet companies will be expected to rely on their own characteristics to construct industrial Internet platforms, incubate independently operated platform services, and export industrial Internet platforms with certain security capabilities to other companies. (3) Security companies will use their accumulated security experience to provide security solutions for industrial Internet platforms. In addition to traditional security functions such as asset mapping, antivirus software, firewalls, intrusion detection, traffic auditing, security monitoring, etc., they will also export security capabilities through software-as-a-service models, to provide technical support for the industrial Internet platform. (4) Relying on the advantages of systems and software expertise, Internet companies will provide industrial Internet platforms with secure operating systems, virtualization software, databases, and big data analysis models. (5) Hardware companies will develop hardware devices with integrated security capabilities, such as industrial control equipment, secure routing, security gateways, secure edge nodes, and trusted servers to provide hardware-based security protection capabilities for industrial Internet platforms.

4.2 Application scenarios of four types of basic technologies empowering intelligent manufacturing

4.2.1 Horizontal application scenarios of intelligent manufacturing enabled by industrial big data and AI technology

The horizontal application scenarios of industrial big data technology empowering intelligent manufacturing

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may be considered in terms of five principle aspects, the first of which is intelligent design based on industrial big data. This approach integrates the knowledge resources required in each link of product lifecycle design into various design processes by using big data-related technologies, displays the relationship between big data on the product lifecycle and design in a highly orderly manner, and also develops product design knowledge, improve the efficiency and quality of R&D operations, and support collaborative design. The second factor is intelligent production based on industrial big data. Under this approach, data such as equipment operation, process parameters, quality inspection, material distribution, and progress management, is collected from production site operations and analyzed to apply big data technology to manufacturing and production processes, as well as to quality management, equipment maintenance, energy consumption management, and other specific scenarios to optimize the production process. The third is networked collaborative manufacturing based on industrial big data, which is reflected in collaborative R&D and manufacturing, optimization of supply chain management systems, and optimization of manufacturing capacity resources. The fourth factor of interest is intelligent services based on industrial big data. The integrated application of industrial big data and next-generation technologies is expected to provide new content across the whole lifecycle services of products such as marketing and sales as well as operation and maintenance, from large-scale assembly line production to large-scale customized production, and from production-oriented to service-oriented manufacturing. The fifth factor is personalized customization based on industrial big data. The combination of industrial big data and a large-scale personalized customization model supports the individualization of industrial product development, equipment management, enterprise management, personnel management, and vertical industries, forming a new model of industrial value creation.

Similarly, the horizontal application scenarios of AI technology empowering intelligent manufacturing mainly involve three aspects. The first important factor is the AI-enabled optimization and intelligent design of product and production lines. AI technology is expected to be utilized to model products and productions, and AR/VR and other technologies are used to realize data fusion of virtual and physical models, while simulation optimization technology will be used to carry out closed-loop iterative optimization of products and production lines, which will ultimately support the simulation, analysis, and optimization of manufacturing system product and production lines. Second, AI vision empowers intelligent monitoring and detection. To address the needs of intelligent data analysis in the manufacturing process, data-driven models of industrial mechanisms can be created, industrial big data intelligently processed, and equipment monitoring, inspection, emergency troubleshooting, process quality inspection, etc. can be carried out. The third factor is AI-enabled intelligent management and control. Technologies such as big data and knowledge graphs will support enterprises to optimize the operational efficiency of the supply chain in terms of sales, procurement and other links, and finally realize the cloud-based visual intelligent management and control of all equipment. This will also enable the construction of smart industrial chain application models with the full lifecycle of products and the coordination of all elements of the supply chain. Fourth, big data will intelligently empower remote operation and maintenance services. This will support the realization of intelligent services such as cloud-based intelligent monitoring, fault diagnosis, and remote operation and maintenance. AI and other technologies can be used with big data to build algorithmic models for tasks as equipment management, operating condition monitoring, and fault diagnosis, as well as remote operation and maintenance.

4.2.2 End-to-end application scenarios of intelligent manufacturing enabled by 5G, modeling, simulations, and digital twin technologies

The end-to-end application scenarios of 5G technology enabling intelligent manufacturing mainly involve three aspects. First, 5G empowers cloud-based smart devices, with cloud-based industrial robots as a typical example. Starting from a control platform located in the cloud, and using AI, big data and other technologies to control local robots to perform tasks, these technologies can enable the realization of remote real-time control of robots and strengthen their ability to cooperate with each other, to enable robots to cooperate with people more agilely and safely. The second is 5G-enabled industrial VR, which is mainly used in virtual assembly, virtual training, virtual exhibition halls, and other scenarios; VR virtual assembly can optimize the energy efficiency of the actual assembly of products in aspects such as design interfaces and component appearance, while VR virtual training scenarios are more intuitive and information is transferred more abundantly. VR virtual exhibition hall allows visitors to engage with an on-site remote experience. Third, 5G enables real-time data collection and monitoring, facilitates real-time uploading of massive data in factories, supports ultra-high definition video surveillance and machine vision recognition, and enhances the remote operation and maintenance capabilities of factory equipment.

Modeling simulation and digital twin technology enables end-to-end application scenarios of intelligent manufacturing. Around the whole lifecycle activities such as demonstration, research, analysis, design, production, management, testing, operation, training, evaluation, sales, service, and destruction, and based on models and data-driven methodologies, people, physical spaces, and information or cyberspaces can be connected as an organic whole to enable people, machines, objects, environment, information, and other elements to perceive, learn, analyze, make decisions, and execute actions autonomously and intelligently. Multidisciplinary simulation research and development of products based on modeling simulation and digital twin technologies, parallel product design based on modeling simulations and digital twins, and remote operation and maintenance of products based on digital prototype are the main application scenarios of these technologies in this context.

5 Suggestions for the development of information and communication technologies to enable intelligent manufacturing

5.1 Technical advice

In terms of technology research, the following technologies are of considerable interest: 5G advanced networks, collaborative computing, and cross-chain knowledge construction; high-end new industrial big data core software technologies such as modeling of industrial mechanisms via big data and knowledge reasoning; core industrial Internet system technology such as IoT technology innovation systems, the CPS core support technology, cloud demonstration/cloud design/cloud simulation/cloud production /cloud experiment/cloud management/cloud service integration application technology, high-performance simulation computer technology, core architecture technology of industrial chain block, and industrial intelligent sensor technology; deep integration of AI and industrial technologies; and modeling simulation and digital twin core technologies for new intelligent manufacturing systems that are digital, networked, cloud-based, and intelligent.

In terms of industrial development, it is recommended to focus on the R&D and industrialization of the following aspects: (1) 5G application and network collaboration; (2) new industrial big data platforms and industrial supply chain data collaborative sharing platforms; (3) multi-scenario-oriented industrial resource, capability, and product intelligent components and APPs, AI IoT device–pipe–cloud integrated platforms, industrial software for industrial CPS, edge manufacturing and high performance simulation computer toolsets (hardware and software), cloud data center operation services, autonomous and controllable blockchain public service platforms, industrial collaborative security platforms, cloud PLC/DCS, and intelligent microsystem platforms; (4) smart products and smart interconnected products for the new generation of AI technology; and (5) autonomous and controllable modeling and simulation and digital twin toolsets and system products.

In terms of application demonstration, it is recommended to focus on demonstrating the following applications: (1) industrial design based on 5G + industrial VR; (2) network applications of data fusion systems for enterprise interconnection; (3) industry public service platforms, AI IoT industrial platforms, CPS basic services for typical industries, intelligent industrial edge control based on cloud–edge collaboration, intelligent high-performance simulation cloud computing systems for CPS engineering, and industrial control data security collection based on blockchain technology; (4) cloud–side–end collaborative manufacturing cloud on cloud-native AI platforms; and (5) intelligent design of industrial products based on modeling simulation and digital twin technology.

5.2 Strategic advice

Based on this work, we conclude that decision-makers should undertake to improve the efficiency and coordination of policy promotion working mechanisms for new intelligent manufacturing applications, and construct an integrated development model for major new developments in information and communication technology industries such as 5G, big data, the industrial Internet, AI, and digital twin systems to provide a solid foundation to support new intelligent manufacturing. Decision-makers should establish a market-oriented mechanism for technological innovation, highlight the main role of enterprises in innovation, promote the aggregation of various innovation elements to enterprises, form a market-oriented technological innovation system with enterprises as the main body, and focus on the combination of production, education, research, and application, while striving for breakthrough in key core technologies and system integration technologies.

Moreover, decision-makers should accelerate the formulation and revision of basic commonalities and key technical standards related to new intelligent manufacturing, involving system construction, integrated applications, industrial ecology, and industry supervision, and promote the formation of a standards group in which national standards, industry standards, collective standards, and enterprise standards may be coordinated in a complementary manner. They should pay attention to the effect of standards implementation and support industrial enterprises to carry out standardized intelligent workshop and factory construction and enhance the deep integration of data and standards in the field of new intelligent manufacturing, such as security, technology evaluation, and industrial identification analysis. Decision-makers at all levels of enterprises and regulating authorities should actively participate in international standardization work, and should promote the simultaneous development of national standards with high technical readiness and international standards.

Leading enterprises in the industry should be supported to unite with universities, research institutes, upstream and downstream enterprises, and to jointly build a national industrial innovation center. Moreover, qualified enterprises should be encouraged to jointly transform into scientific research institutes and set up industry research institutes to provide common technical services for public welfare. A new common technology platform should be created to solve key common technical problems across industries and fields in the industrial environment. In this context, decision makers should consider the leading and supporting roles of large enterprises, support innovative small, medium, and micro enterprises to grow into centers of innovation, and promote the integration and innovation of large, medium, and small enterprises in the upper, middle, and lower reaches of the industrial chain. The construction of computing infrastructure such as industrial data centers and intelligent computing centers should be strengthened to support the application of new AI technologies. Large enterprises and industrial parks should be promoted to establish industrial Internet platforms with their own characteristics, which involves internal resource integration, product lifecycle management, industrial chain supply chain coordination, and small and medium-sized enterprise services to support the realization of the effective integration and management of all elements of intelligent manufacturing and data across the entire industrial chain.

Moreover, decision makers should aim to enhance the deep integration of industry and education in the field of intelligent manufacturing. Relevant enterprises in the fields of ICT and intelligent manufacturing should be encouraged to participate deeply in the formulation of professional teaching standards and talent training plans, the development of teaching resources, and the implementation of courses, thus to establish a smooth school–enterprise cooperation mechanism. The training system for innovative digital talents should be optimized, and professional development projects for professional and technical personnel should be deeply implemented. Advanced training programs should be organized and implemented around key industries such as 5G, industrial Internet, big data, and AI, and talented in-demand professional and technical personnel should be trained on a large scale. Global digital talent projects should be implemented to meet the needs of high-end talents in related fields and attract a wide variety of talented personnel to engage in basic and applied research in the emerging field of intelligent manufacturing.

References

[1] Xinhua Net. Outline of the 14th Five-Year Plan for national economic and social development of the People’s Republic of China and the vision for 2035 [EB/OL]. (2021-03-13)[2022-02-15]. http://www.xinhuanet.com/2021-03/13/c_1127205564.htm. Chinese.

[2] Li B H, Chai X D, Zhang L, et al. Accelerate the development of intelligent manufacturing technologies, industries, and application under the guidance of a new-generation of artificial intelligence technology [J]. Strategic Study of CAE, 2018, 20(4): 73–78. Chinese.

[3] Li B H, Chai X D, Hou B C, et al. Cloud manufacturing system3.0—A new intelligent manufacturing system in the era of “Intelligence +” [J]. Computer Integrated Manufacturing Systems, 2019, 25(12): 2997–3012. Chinese.

[4] Li B H, Chai X D, Hou B C, et al. A new type of industrial Internet - Intelligent industrial Internet [J]. China Industry & Information Technology, 2021 (6): 54–61. Chinese.

[5] Ministry of Industry and Information Technology of the People’s Republic of China. China’s 14th Five-Year Plan for the deep integration of informatization and industrialization [EB/OL]. (2021-11-17)[2021-12-31]. https://www.miit.gov.cn/jgsj/xxjsfzs/zlgh/art/2021/art_adc18bc1dd4946838828ea129afc433e.html. Chinese.

[6] People’s Daily Online. The annual Central Economic Work Conference was held in Beijing [EB/OL]. (2021-12-11)[2022-02-15]. http://cpc.people.com.cn/n1/2021/1211/c64094-32305295.html. Chinese.

[7] Ministry of Industry and Information Technology of the People’s Republic of China. Industrial Internet encyclopedia entry[EB/OL]. (2021-7-29)[2021-12-31]. https://www.miit.gov.cn/jgsj/xgj/gzdt/art/2021/art_3cffba8810be4ec68bc3d1051a0c0453.html. Chinese.

[8] Alliance of Industrial Internet. Industrial Internet platform white paper(2017). [EB/OL]. (2017-12-01)[2021-12-31]. http://www.aii-alliance.org/index/c145/n94.html. Chinese.

[9] Sengupta J, Ruj S, Bit S D. A comprehensive survey on attacks, security issues and blockchain solutions for IoT and IIoT [J].

Journal of Network and Computer Applications, 2020, 149: 1–15.
[10] China Electronics Standardization Institute, China Information Physics System Development Forum. Information physical systems white paper(2017) [EB/OL]. (2017-03-02)[2021-12-31]. http://www.cesi.cn/201703/2251.html. Chinese.
[11] China Electronics Standardization Institute, China Information Physics System Development Forum. Guidelines for building information physical systems(2020) [EB/OL]. (2020-08-28)[2021-12-31]. http://www.cesi.cn/202008/6748.html. Chinese.
[12] Ministry of Industry and Information Technology of the People's Republic of China. Cloud computing white paper(2012) [EB/OL]. (2012-04-03)[2022-02-15]. http://www.caict.ac.cn/kxyj/qwfb/bps/201804/P020151211378881360681.pdf. Chinese.
[13] Gao Y, Huang X K, Li X W, et al. Cloud computing security requirements and measurement practices in the classified protection 2.0 era [J]. Journal of Information Security Research, 2018, 4(11): 987–992. Chinese.
[14] Edge Computing Consortium. Edge Computing Industry Alliance white paper [EB/OL]. (2016-11-30)[2021-12-31]. http://www.ecconsortium.org/Lists/show/id/32.html. Chinese.
[15] China Academy of Information and Communications. Blockchain white paper(2018) [EB/OL]. (2018-09-08)[2021-12-31]. http://www.caict.ac.cn/kxyj/qwfb/bps/201809/t20180905_184515.htm. Chinese.
[16] China Academy of Information and Communications Technology, Alliance of Industrial Internet. Industrial blockchain application guide [EB/OL]. (2020-09-08)[2021-12-31]. https://mp.weixin.qq.com/s/mrxXX_UIMsEs0tDeTJBcbA. Chinese.
[17] Mayer-Schönberger V, Cukier K. Big data: A revolution that will transform how we live, work and think [M]. Translated by Zhou T. Hangzhou: Zhejiang People's Publishing House, 2013. Chinese.