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Key Technologies of Intelligent Products and Equipment Led by New-Generation Artificial Intelligence

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Abstract: Intelligent products and equipment are the value carriers, technological prerequisites, and material bases of intelligent manufacturing and service. Intelligent products and equipment refer to two dialectical aspects. First, a commercialization of intelligent technology, turning intelligence technology into products, which is mainly reflected in the comprehensive application of the Internet of Things, big data, cloud computing, edge computing, machine learning, deep learning, security monitoring, automation control, computer technology, precision-sensing technology, and GPS positioning technology. Second, intelligent products and equipment also refer to the intellectualization of traditional products. New-generation artificial intelligence endows traditional products with higher intelligence and injects vitality and developmental motivation into traditional products; this is achieved through intelligent manufacturing equipment, intelligent production, and intelligent management. Based on extensive scientific surveys and current research, along with a consideration of the ten major fields of *China Manufacturing 2025* and macro policies, such as the *Three-Year Action Plan for Artificial Intelligence*, twelve major intelligent product and equipment fields are formulated. Research shows that new-generation intelligent products and equipment focus on knowledge engineering and are prominently characterized by self-sensing, self-adaptation, self-learning, and self-decision-making. Ten key technologies will be prioritized in the future.

Keywords: intelligent products and equipment; knowledge engineering; intelligent state sensing; intelligent variation adaptation; intelligent knowledge learning; intelligent control decision

1 Importance and value of intelligent products and equipment

1.1 Importance of intelligent products and equipment

1.1.1 Development status of the global intelligent manufacturing industry

Since the steam revolution in the 18th century, products and equipment have undergone development in terms of mechanization, electrification, informatization, and intelligentization. Since the beginning of the 21st century, breakthroughs made in the fields of Internet, big data, cloud computing, new materials, new energy, life sciences, among others, have extended the frontiers of knowledge. At present, the global manufacturing landscape is undergoing a major adjustment; China's manufacturing industry is transforming and upgrading, and is presented with a major opportunity for innovative design development [1–2].

At present, every country in the world attaches great importance to technology pushing the intelligent frontier. "The Advanced Manufacturing Partnership" and the "Manufacturing

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Return to the United States" are strategies that strongly express the determination of the U.S. to revitalize its manufacturing industry; these strategies identify intelligent manufacturing as the main driving force for the overall revival of the U.S. manufacturing industry. German Industry 4.0 uses the Cyber Physical System to digitize production supply, manufacturing, and sales information to achieve a fast, effective, and personalized product supply. Emphasis is placed on three themes: intelligent factories, intelligent production, and intelligent logistics. In addition, the technical basis of this strategy is the network entity system and the Internet of Things. A research report titled "Advanced Production Equipment Research Roadmap" predicts that, between 2010 to 2030, the development of advanced machine tools and systems will involve six fields, 24 key enabling characteristics, and 42 technical subfields involved.

In recent years, the United States, Germany, Japan, and other developed countries have created representative intelligent products and equipment to enhance the competitiveness of their manufacturing industries. For example, Apple's iPhone includes: the smart voice service, Siri; smart graphics and image processing; smart face recognition and verification; and the A11 bionic chip. The Boston Dynamics Dog, a four-legged, dog-shaped robot in the United States, has tremendous stability that enables it to handle many unanticipated challenges. Leonardo Da Vinci surgical robots, developed jointly by several companies in the United States, include three major systems: a surgeon console; a robotic arm system; and an imaging system. These robots are suitable for urology, cardiothoracic surgery, gynecology, and abdominal surgery. Siemens' Intelligent Gas Turbine can intelligently monitor itself. The company analyzes the data collected by more than 5,000 sensors on the gas turbine using big data to ensure operation safety and provide maintenance decisions. A gas turbine generates 30 GB of sensor data per day. Using intelligent analysis, Siemens can judge whether the gas turbine needs to be repaired, which reduces the amount of maintenance-related downtime for its customers. In Japan, Fanuc has developed a self-learning, intelligent robot that learns to place its own work piece without human guidance. In the first step, the robot grasps a work piece randomly; in the second step, it judges its own success/failure and collects pictures for training; in the third step, after a long period of learning, there is progressive improvement in the accuracy of task execution.

1.1.2 Development status of the intelligent manufacturing industry in China

Equipment manufacturing plays a decisive role in the development of industry, agriculture, energy, transportation, information, water conservancy, urban and rural construction, the modern service industry, and national defense security. It can be considered as the basic strategic pillar for national economic development. Intelligent products and equipment are the value carriers of intelligent manufacturing and service, besides being the technical premise and material basis for intelligent manufacturing.

The report on the 19th National Congress of the Communist Party of China clearly states that supply-side structural reform should be deepened, to make China powerful in terms of manufacturing by accelerating the development of an advanced manufacturing industry, promoting a deep integration of the Internet, big data, AI, and the real economy; further, it stresses the need to cultivate new growth points and generate new momentum in high-end consumption, innovation leadership, green and low-carbon manufacturing, the shared economy, modern supply chains, human capital services, and other fields. We should support the upgrading of traditional industries and accelerate the development of modern service industries. This should be done with the aim of matching international standards, promoting the shift in China's industry towards the high-end of the global value chain, and cultivating a number of world-class advanced manufacturing clusters. The Ministry of Industry and Information Technology emphasizes the deep integration of AI with the real economy and manufacturing, the development of intelligent products and equipment, and the promotion of the overall upgrading of China's manufacturing products and equipment to "intelligent generation," which is one of the keys to the implementation of the *China Manufacturing 2025* initiative.

Traditional manufacturing has low intelligence, low collaboration efficiency, slow demand response, high costs, and weak competitiveness. More serious issues are that high-end products rely on imports and there is an oversupply of low-end products. Therefore, deepening supply-side structural reform is imperative. Intelligent manufacturing led by AI 2.0 (the new-generation AI) [3−4] applies the Internet, big data, and cloud computing technologies to achieve highly collaborative and efficient manufacturing, a rapid response to customer needs, and significantly enhanced competitiveness.

Therefore, to achieve the historic transformation from a country with a big manufacturing base to a great power in manufacturing, intelligent products and equipment must come first. From imitation to innovation and from tracking to guidance, China must have a scientific and forward-looking vision as well as plans for long-term development. Intelligent products and equipment play an important role in supporting, leading, and demonstrating intelligent manufacturing led by AI 2.0.

1.2 Value of intelligent products and equipment

1.2.1 To become an important strategy for the development of the manufacturing industry

Big data, intelligent production, and mobile networks have pushed into the era of AI 2.0 [5], making profound changes in economic configuration. Breakthrough technological innovation is recognized as the direction of technology and

industrial development. In addition, it is also the key means for the country to enhance its comprehensive national strength and achieve its target of catching up with worldwide technological and industrial development. Internet, cloud computing, and big data are profoundly changing the development mode of the manufacturing equipment industry. Information is highly unimpeded, productivity is highly developed, the proportion of product manufacturing in the value chain is declining, and the proportion of product design in the value chain is rising significantly. Market boundaries continue to extend, emerging markets continue to open up, product connotations are changing, the value of intellectual resources and big data-derived knowledge is prominent, and customer experience and participation in creative design is improving.

The intelligent technology industry can apply various kinds of terminals with environmental perception abilities to every link of industrial production with ubiquitous technology-based computing models and mobile communication. This greatly improves manufacturing efficiency and product quality, reduces product cost and resource consumption, and moves the traditional industry to a higher stage of intelligence.

1.2.2 To promote the transformation from a manufacturing country to a manufacturing power

On the basis of the implementation of digital networking, a new generation of AI technology is integrated to upgrade systems, bring economic benefits and competitiveness to users and manufacturers, and promote the transformation of China from a big country to a powerful one. The main symbols of this change are: (1) its world-leading international market share; (2) the international competitiveness of its important industries, based on gross industrial output value, is among the best in the world and they have a considerable influence on global supply and demand; (3) it possesses a number of "flagship" international industries that have international influence, capital, and technology export capability, besides being ranked among the top 500 in the world. (4) it possesses a group of world-class intelligent equipment manufacturing bases whose international competitiveness and market share match the best in the world.

2 Connotation, features, and development targets of intelligent products and equipment

Intelligent products and equipment are the combination of AI technology and product equipment; they provide products and equipment with the features of intelligent perception, analysis, decision making, and control.

2.1 The connotation of intelligent products and equipment

Intelligent products and equipment can refer not only to the production of intelligent technology, but also to the intelligence of traditional products.

2.1.1 The productization of intelligent technology

Intelligent technology is based on the application of the IoT, big data, cloud computing, edge computing, machine learning, deep learning, augmented reality, security monitoring, automation control, computer technology, precision sensing technology, and GPS technology. Intelligent integration into traditional industries is a trend in the new economy. With the progress in intelligence and information technology, the real economy will be able to achieve new breakthroughs. The productization of intelligent technology can greatly improve the operator's working environment and reduce the intensity of work. It can also improve work quality and efficiency, diffuse some dangerous situations and key construction applications, and improve the degree of automation and intelligence of the machine; this helps in the better protection of the environment and energy saving. Realizing intelligent diagnosis abilities improves the reliability of equipment, reduces maintenance costs, and enhances the competitiveness of products.

2.1.2 Intellectualization of traditional products

Traditional intelligent products can take advantage of the Internet to endow other products with intelligence. Intelligent ideas can be integrated into traditional products to inject vitality into intelligent manufacturing equipment, intelligent production, intelligent management, and the enterprises that produce traditional products. The intellectualization of traditional products involves research on how to apply AI technology to improve the integration ability of intelligent manufacturing systems for equipment. To achieve intelligent production, systems for manufacturing execution, distributed control, and digital control are widely used to improve the quality of equipment for online monitoring and the remote monitoring of status diagnosis and analysis. For intelligent management, intellectualization promotes the production, sales, business, and finance functions, besides leading to synergy between upstream and downstream enterprises in the industrial chain. To provide intelligent service, intellectualization develops new manufacturing modes based on the internet and forms enterprise design, production, supply-chain management, and service systems based on the customization of individual demands. Major process machinery, such as intelligent separation equipment, intelligent pressure reflecting equipment, intelligent early warning systems, intelligent control, and intelligent explosion prevention, can achieve significant results by drawing on their intelligent features.

This research mainly studies the intellectualization of traditional products, that is, the upgrading of the traditional equipment manufacturing industry with "intellectualization +," which promotes new growth points and creates new energy.

2.2 Features of intelligent products and equipment

Intelligent products and equipment utilize knowledge engineering as their core [6]. Their prominent features include self-sensing, self-adaptation, self-learning, and self-decision-making. Knowledge engineering is an important theoretical basis for the new generation of AI. Its fundamental purpose is to develop AI systems, supply and expand the functions of the brain, and create an era of human-computer interaction.

Self-sensing is the technology based on intelligent induction, perception, and recognition of signals. A sensor is a kind of detection device that can sense the measured information and transform the sensed information into electrical signals or other required forms of information output, according to certain rules that meet the requirements of information transmission, processing, storage, display, recording, and control. Self-sensing is the basis of self-adaptation, self-learning, and self-decision-making.

Self-adaptation is an intelligent adaptation to a multi-task environment, as well as to multi-machine collaborative-cluster interaction and control. A self-adapting technology can modify its own features to adapt to changes in the dynamic features of objects and disturbances. Self-adaptation can determine the actual working state of the controlled object, optimize the performance criteria, and generate adaptive control rules by continuously collecting control process information from the system's operation; this helps in adjusting the structure or parameters of the mechanical system in real time, and makes the system work automatically in an optimal or sub-optimal operational state.

Self-learning refers to the ability to improve a control algorithm according to the technology's own experience of the operational process. It is an extension and development of self-adaptation systems. Self-learning can automatically modify the system structure or parameters to improve the quality of the system by evaluating the correctness of the existing behavior. Unlike self-adaptation systems, these learning improvements can be preserved and fixed in the system structure, which is easy to implement and can be used as a method of intelligent design or adjustment.

Self-decision-making refers to the ability to continuously execute a series of control functions in unstructured environments, which can organically combine the sensing, decision making, coordination, and action capabilities of autonomous control systems without human intervention. Self-decision-making intelligence is based on AI and includes concepts such as machine autonomy, people-assisted machines, man–machine negotiation, machine-assisted people, and fully manual decision-making methods.

2.3 Development targets for intelligent products and equipment

Intelligent manufacturing has certain stage-wise or short-term targets. The targets are important for intelligent manufacturing to achieve intelligent products and equipment and enhance the international competitiveness of China's manufacturing industry.

Target in 2025: AI 2.0 system technology will have been successfully applied to typical products and equipment, and significant progress will have been made in the digitization, networking, and intelligentization of products and equipment. Breakthroughs will have been made in the fields of: self-diagnostic injection-molding equipment; green, low-carbon energy-saving excavation equipment; multi-condition adaptive compressor units; intelligent robots with human-machine integration; high-security, intelligent network vehicles; intelligent mobile phones with a deep integration of AI; and so on. All of these will play a pivotal role in the development of intelligent products and equipment.

Target in 2035: A deep integration of AI 2.0 technology and equipment will have been achieved. In addition, a number of leading international, intelligent products and equipment with key core technologies will have been mastered. Intelligent machine tools and equipment, intelligent engineering machinery, intelligent power equipment, intelligent robots, intelligent delivery equipment, and intelligent terminal products made in China will have self-induction, self-adaptation, self-learning, and self-decision-making features. These will provide a world-leading advantage. China's overall competitiveness will be that of a world power.

3 Twelve fields of intelligent products and equipment

The ten key fields of *China Manufacturing 2025* include new generation information technology, high-grade computer numerical control and robots, aerospace equipment, marine engineering equipment and high-tech ships, advanced rail transit equipment, energy-saving and new energy vehicles, power equipment, new materials, biomedicine and high-performance medical equipment, and agricultural machinery and equipment. The Ministry of Industry and Information Technology has implemented a three-year plan of action for AI, and it has clearly put forward eight intelligent products: intelligent network vehicles, intelligent service robots, intelligent unmanned aerial vehicles, medical-image-aided diagnosis systems, video-image identification systems, intelligent voice interaction systems, intelligence systems, and smart home products.

Considering the ten major equipment types of *China Manufacturing 2025* and the application of AI in the field of intelligent manufacturing in recent years, and highlighting the cluster development of the equipment-manufacturing industry chain, this research proposes the following twelve major fields on the basis of extensive scientific research and existing research: intelligent machine tool equipment; intelligent thermal and raft equipment; intelligent power and energy equipment; intelligent engineer-

ing machinery; intelligent aviation and aerospace equipment; intelligent marine engineering and ship equipment; intelligent robot; intelligent rail transit and transport equipment ; intelligent connected vehicle; intelligent agricultural machinery; intelligent home products; and intelligent terminal products [6−10]. The twelve fields can converge to the following six priority fields for industry convergence: intelligent machine tool equipment, intelligent engineering machinery, intelligent power equipment, intelligent robots, intelligent transport equipment, and intelligent terminal products.

3.1 Intelligent machine tool equipment

Machine tools are the basis of manufacturing. A computer numerical control machine tool is a machine that usually processes metal by cutting, grinding, milling, and so on. General machine tool equipment includes cutting and shaping machine tools, casting equipment, welding equipment, injection-molding equipment, and so on. Intelligent machine tools can understand the whole manufacturing process and make decisions on work processes using error compensation. They can monitor, diagnose, and correct various deviations arising from production process. Additionally, the tools can provide optimized solutions for production.

3.2 Intelligent engineering machinery

Intelligent engineering machinery includes tunneling equipment, excavation equipment, and agricultural equipment, and it can be further subdivided into more than ten kinds of production, such as excavating machinery, earthmoving machinery, compaction machinery, pavement construction and maintenance machinery, tunneling machinery, concrete machinery, sanitation machinery, lifting machinery, road engineering machinery, farm machinery, and so on.

AI 2.0 plays a vital role in the development of engineering machinery. Intelligent engineering machinery, characterized by high precision, high efficiency, energy saving, intelligent manipulation, and remote cluster control, is the future development trend. Facing the market economy and global competition, advanced manufacturing technology and high-end products have become the sources of core competitiveness in engineering machinery. Technological foresight related to engineering machinery, especially mechatronics and hydraulics integration equipment, has great significance.

3.3 Intelligent power equipment

Power equipment is used to transform, transmit, and adjust all kinds of potential energy in nature for use by mankind. The field of intelligent power and turbo-machinery equipment includes compressors, steam turbines, and gas combustion turbines. Compressors are a key industry and are needed for national energy development. Steam turbines are important power devices that are widely used in the industrial field and consume a lot of energy. Compared with steam turbines, gas combustion turbines have a higher energy density and more technological features. Technological foresight related to power equipment, especially highly reliable and intelligent equipment, has great significance.

3.4 Intelligent robots

An intelligent robot is a robot that has perception; it can think and display intelligent behavior. In addition, it can acquire, process, and identify multiple kinds of information. An intelligent robot can complete complex operation tasks by itself. It is based on the development of computer technology and an interdisciplinary science. As a new generation technology used in production and providing service, it has wide and important applications in the manufacturing field. Technology foresight into intelligent robots, especially intelligent robots that fuse multiple sensors is of great significance.

3.5 Intelligent transport equipment

Intelligent transport equipment includes intelligent green trains, unmanned aerial vehicles, and so on. The intelligence is mainly reflected in system-wide security, energy conservation, environmental protection, digitalization, intellectualization, and networking. Next-generation rail transit systems are green, intelligent, high-speed, and able to haul heavy loads. Research into the system life cycle provides users with overall solutions and will help establish the world's leading modern rail-transportation industry system. Therefore, technical foresight into rail transit equipment, especially highly safe and comfortable equipment, is of great significance.

3.6 Intelligent terminal products

Intelligent terminal products include smart phones, smart wearable devices, and so on. The core of an intelligent terminal product is its operating system and intelligent applications (Apps). With the rise of mobile Internet (MI), supported by 4G and 5G networks, the number of users of intelligent terminal products is increasing rapidly. Further, access to MI and intelligent terminal products has become easier. Therefore, technological foresight related to terminal products, especially highly integrated ones, is of great significance.

4 Key technologies of intelligent products and equipment

The new generation of AI (also known as AI 2.0) has received unprecedented attention not only in China, but also around the

world. As the value carriers, technological prerequisites, and material bases of AI 2.0, intelligent products and equipment incorporate the most advanced technology.

4.1 Multi-source multi-channel real-time data acquisition and sensing technology

Multi-source multi-channel real-time data acquisition and sensing technology collects multi-source sensor data from products across time, region, physical space, and network space. Additionally, the technology achieves lossless transmission throughout the whole process of remote encryption, compression, transmission, reception, parsing, and conversion. Data, integration software, and integration rules are the three indispensable basic conditions for data integration. Data is the object of integration. Integration software is either a software tool that can handle spatial features, as well as attribute characteristics and their associations, or a software designed specifically for data integration that can implement most of the operations involved. Integration rules are the basis for data integration. The equipment usually obtains outside information through various sensors. Sensing is the real-time detection of the equipment's internal movement and working conditions, as well as information on the external working environment. Because the sources, reference systems, and parameters are quite different, sensing data needs to be matched by a series of transformations and uniform operations. The multi-source information on equipment running conditions collected by sensors is sent to the data center through wired and wireless sensor networks for analysis and processing. In addition, this information supports the intelligent optimization of the decision making on equipment operation status analysis, diagnosis, early-warning, inspection, and operating maintenance. After comparing the feedback to the control system with the specified information, the actuator is adjusted to ensure that the equipment's work meets the predetermined requirements.

4.2 Heterogeneous metadata fusion and transmission sharing technology

Heterogeneity is ubiquitous in information systems. It is an obstacle to information sharing and interoperability between information systems. To obtain heterogeneous data from multiple sensors, real-time distribution and fusion should be carried out. Feature information is extracted and transformed into a knowledge base by an inference engine that can realize the intelligent integrated perception of product equipment. From the sensing layer to the application layer of the IoT, the kinds and quantities of sensor information multiply, and the quantity of data needing analysis also increases dramatically. At the same time, data fusion between heterogeneous networks or multiple systems is also required. Heterogeneous data from multiple sensors needs to be analyzed and fused in real time to extract feature information. Using the inference engine, the features are matched with knowledge in the knowledge base to realize the intelligent integrated perception of products and equipment. The data and information from multi-sensor sources are combined to obtain more accurate feature recognition and realize the process of real-time and thorough evaluation of targets. Through content analysis and the fusion processing of various heterogeneous data, hidden information and effective data are mined from mass data to improve the accuracy of operating condition monitoring by intelligent products and equipment. Using the inference engine, the feature information that is extracted from heterogeneous metadata fusion is matched with knowledge in the knowledge base to realize the intelligent identification of product and equipment status. Lossless transmission of heterogeneous data and its fusion information is achieved throughout the process of remote encryption, compression, transmission, reception, and parsing to realize the sharing of metadata across time, region, physical space, and network space.

4.3 Multi-task adaptive collaborative technology under various working conditions

Intelligent products and equipment can independently analyze the current task requirements, and adaptively adjust the operational strategy according to varying task difficulties and working conditions. Cooperative execution leads to a multi-objective optimization model that considers the maximum profit-loss ratio and task balance; the model is solved by using an optimization algorithm, and cooperative task planning between different products and equipment is achieved. Intelligent products and equipment adapt operation strategies and implementation schemes according to the task requirements and difficulties assigned in planning, thereby accomplishing various tasks under complex working conditions. In addition, they automatically and intelligently determine the working state of a specific equipment under conditions directly related to its operation. According to the coupling mechanism and adaptive decoupling technology of big data and the multi-field of complex equipment, intelligent self-adaptive technology can process parameters for working conditions that achieve a fast, iterative solution using big data and multi-field coupling; further, it establishes the local function defect diagnosis model and achieves visual simulation and diagnostic analysis.

4.4 Cluster interaction and control technology for multi-machine collaboration

Intelligent, multi-machine clusters simulate the behavior of biological clusters. Individual computers work together through mutual information interaction and autonomous control, thus completing diverse and complex tasks at low cost in various complex environments. The cluster operation of multi-machine

collaboration has high execution efficiency and strong robustness. It can distribute tasks to different clusters for processing to avoid high computational complexity within a single machine. At present, it is still difficult to accomplish special tasks by depending on the capability of a single machine. Group decision making and operation in complex and novel environments is an important milestone for future intelligent equipment technology. This requires the simultaneous execution of rules for multiple machines. Further, it involves the analysis of the functions and attributes of various machines and the coordination of many machines; these can improve the real-time judgment and decision-making capabilities of machines. A simpler and more humanized intelligent human-machine interface can carry out various intelligent tasks proposed by different users, such as the recognition of handwriting, understanding an image or language, and the recognition of different languages.

4.5 Deep learning and fault diagnosis technology driven by big data

The establishment of a reliable health management system for equipment is a necessary measure to ensure safe operations. Owing to large-scale equipment, lengthy monitoring time, and the high sampling frequency of each monitoring point, the whole monitoring system generates a large amount of data; thus, equipment status diagnosis and health management has entered the era of big data. Traditional equipment condition diagnosis methods need a lot of engineering practice and signal processing technology to extract fault feature information. In the training of a condition diagnosis model, a shallow model has difficulty solving problems of equipment faults with greater amounts of data, and the model's ability to monitor and diagnose a condition is obviously insufficient. Depth learning uses equipment-measured data to train a depth learning network. Through the construction of a deep-level model, combined with a large amount of training data, the implicit characteristics of the data can be mastered. Through the output level classifier, the intelligent diagnosis of equipment fault types can be completed. As a frontier achievement in the field of pattern recognition and machine learning, big-data-driven condition-diagnosis depth-learning technology has shown its potential in the field of equipment condition diagnosis and health management.

4.6 Performance enhancement design using digital twin and digital mockup

There are many means to complete performance enhancement design, such as digital twin and digital mockup (DMU), which uses the technique of coupled multi-field problems, the Finite Element Method, and computational fluid dynamics. A digital twin is a simulation process that integrates multi-discipline and multi-physical quantities with multi-scale and multi-probability ones by making full use of the physical model, sensor updating, operation history, and other data. According to the mapping in virtual space using AR technology, by reflecting the whole, life-cycle process of the corresponding equipment, a digital twin is fully synchronized with its real state. In the existing DMU methods, owing to machining, assembling and use errors, maintenance, repair, and other factors, the physical domain model cannot be fully consistent with the digital model in the virtual domain, making it difficult to reflect the accuracy of the real product system. Digital twins overcome the limitations of traditional DMU simulation analysis. Performance enhancement design provides intelligent products and equipment with image, video, voice, text, and other metadata processing capabilities, so that intelligent products and machines can fully perceive the environment and human emotions, speech, expression, and so on.

4.7 Optimization and decision-making technology for a multi-technology route work program

An intelligent decision support system is a computer software system based on AI, and especially on the principle and technology of an expert system, which supports the decision making of semi-structured and unstructured problems. The combination of perceptual depth learning with decision-making ability leads to depth reinforcement learning. The combination complements each other and realizes the multi-objective and multi-process autonomous decision making of intelligent products and equipment in design and manufacture. Optimization and decision making of a multi-technology route work program refer to the technology of application information integration and intelligent control. This technology enables equipment to have self-sensing, autonomous decision-making, and automatic control functions, the characteristics needed for categorization as intelligent decision making.

4.8 Knowledge push and automatic clamping technology for process equipment

Knowledge push is a timely and active means of knowledge service. Process equipment is a necessary and important basis for all enterprises that manufacture and produce products. The quality of products largely depends on the subordinate or auxiliary technical process equipment. Process equipment is a general term for all kinds of cutting tools, fixtures, measuring tools, molds, auxiliary tools, and workstation tools that are needed for the realization of technological regulations. Automatic clamping process planning is used to analyze the main clamping process planning, such as clamping sequence, times, and force optimization, by using intelligent algorithms, such as graph theory, clustering, and genetic algorithms. This helps to realize the matching of work piece processing characteristics and manufacturing resource capacity. The cooperative pushing and automatic clamp-

ing of process equipment enable a device to collect and upload sensing and visual information; the cloud terminal receives and intelligently analyzes data, makes decisions, and controls the device to achieve autonomous operation; further, the mobile terminal achieves real-time monitoring of the working process and human-computer intelligent interaction.

4.9 Product knowledge graph and knowledge network construction technology

A knowledge graph is a knowledge base with a graph structure; it belongs to the category of knowledge engineering. In contrast to a general knowledge base, a knowledge graph integrates all subjects, and links knowledge units from different sources, and of different types and structures into a graph. It provides a wider and deeper knowledge system that is constantly expanding, based on the metadata of different subjects. Essentially, it is used to systematize and correlate domain knowledge data and visualize knowledge in a graphic way. A knowledge graph is a knowledge system based on an information system. The complex knowledge domain is displayed systematically, in a grid, after data acquisition, data mining, information processing, knowledge measurement, and graphics rendering; this reveals the dynamic development law of a knowledge network in a knowledge domain. Both GE and Siemens have product maps and mature technology. The complex knowledge domain is displayed after data mining, information processing, knowledge measurement, and graph drawing, and the product knowledge graph and knowledge network are generated. Networked sensing equipment is the hardware foundation of the IoT industry. Aiming at multi-source, heterogeneous, massive, and other characteristics, a hierarchical data visualization fusion model is constructed that can deal with the high dimensionality reduction and classification decision-making problems of industrial equipment perception data by achieving the fusion of domain experience, expert experience, and abstract knowledge. Product knowledge graphs and knowledge networks are constructed to achieve knowledge self-optimization modeling and dynamic growth in the manufacturing domain.

4.10 Mech-electro-hydraulic integrated design using cloud knowledge service technology

The integration of mechanics, electronics, and hydraulics refers to the electronic control of hydraulics and the hydraulic control of mechanics. The electronic components receive feedback and control hydraulic pressure in the process consisting of mechanical movement. It is a kind of highly intelligent mechanical-equipment control technology. Compared with ordinary mechatronics, the integration of mechanics, electronics, and hydraulics is more intelligent and complicated. Applying of the integration of these three in modern machinery is of great significance. It can promote the intellectualization of mechanical production, prolong the life of machinery, and improve production efficiency. The key breakthrough is the combination of electronic technology, computer technology, and hydraulic technology that can greatly improve the workability, safety, and convenience of machinery using microcomputer-controlled high-performance and high-reliability hydraulic transmission. The placement of electronic devices and circuits in hydraulic components is also the development trend in current and future machinery. The direct installation of electronic drive circuit and signal processing storage in the shell of the hydraulic components can not only improve the reliability of hydraulic components, reduce piping, reduce pressure loss, and improve efficiency, but also save installation space and facilitate maintenance. Mech-electro-hydraulic integrated design based on the cloud knowledge service can organize its interdisciplinary knowledge in an orderly way by using intelligent cloud computing. In addition, it can push the required design knowledge to the required personnel at the appropriate time to achieve individualization and efficiency in interdisciplinary knowledge services.

5 Conclusions and suggestions

The future development of intelligent products and equipment tends to be green and low-carbon; further, it has the qualities of high energy efficiency, high performance, high reliability, and life cycle optimization. Based on this, the following policy suggestions for developing intelligent products and equipment are proposed.

5.1 Formulate a national development plan for the intelligent products and equipment industry

Intelligent products and equipment are the core requirement for China's manufacturing industry to transform the mode of economic growth. They represent the new direction of future technological and industrial development, and are playing a leading role in China's overall economic and social development. Therefore, it is necessary to formulate an industrial development plan for intelligent products and equipment at the national level that will guide the enterprises manufacturing them to pay attention to AI and intelligent technology, as well as influence the equipment industry to apply and develop AI and intelligent manufacturing technology.

High-end intelligent products and equipment face highly decentralized markets and need guidance and mandatory macro-planning to foster a market environment conducive to high-end intelligent equipment and product applications in the domestic market. Proposing a direction and path for future technology development around the technology of intelligent products and equipment and formulating a road map for intelligent products and equipment is of great significance for guiding the future

development of intelligent products and equipment technology to. The roadmap for intelligent products and equipment technology should analyze the relationship between economic demand and social development, as well as the research and development required. We organize the technology research on the realization of a future market, through the weak links and key technologies, to make goals, application prospects, and market positioning more explicit for intelligent products and equipment. In the process of formulating a technology roadmap for intelligent products and equipment, we should synthesize the opinions and suggestions of experts in the fields of economics and science and technology, as well as those form society and enterprises to form a consensus and strengthen the guidance function and authority of the roadmap.

5.2 Strengthen basic research on intelligent products and equipment

The fundamental reason behind backward manufacturing equipment is the lack of basic research. Research and development into basic design theory, methods, and common technologies for manufacturing equipment should be taken up as a long-term task; further, research and development into a basic common technology for manufacturing equipment should be supported. This will strengthen the multiple efforts to solve basic science problems of manufacturing equipment. The development of basic hardware for intelligent products and equipment in China lags behind the development of the national economy, while the development of basic intelligent software lags behind the development of basic hardware. Inadequate innovation ability in terms of basic intelligent software is one of the bottlenecks in China's large but not very strong manufacturing industry. In recent years, the basic intelligent software in China has developed rapidly, but the overall innovation ability remains weak. The following are the shortcomings in basic intelligent software in China: small scale; poor characteristics; low maturity, especially in terms of adaptability; low degree of integration; insufficient compatibility; and low coordination efficiency. Therefore, obtaining and using basic intelligent software is difficult because there are obvious weaknesses in the field, such as scattered technology, unsystematic specifications, multiple standards, and low integration.

Basic intelligent software is distinct from basic hardware in its connotation; it is abstract, inclusive, and evolutionary. Basic intelligent software is the abstract expression of common technology and has stronger inclusiveness than physical objects; so, it is easy to realize cross-domain applications. Based on the abstraction and solidification of common technology, it is constantly improving and evolving to realize the accumulation of knowledge assets. The basic software of intelligent products and equipment includes basic design software, process software, assembly software, databases, and so on. Basic design software includes program design software, modular design software, simulation design software, and so on. Basic process software includes processing technology, such as forming and detecting processes. Basic assembly software includes tolerance assembly, assembly sequence planning, visual assembly, and so on. Basic databases include parts libraries, module libraries, case libraries, and so on.

5.3 Increase funding for a knowledge base and basic software Apps for intelligent products and equipment

The intelligent product and equipment knowledge base and basic software development tools should be strengthened. A knowledge base is essential. The development of a knowledge base is still relatively weak. A knowledge base and knowledge engineering software are the ultimate crystallization of knowledge and technology content. Real, intelligent manufacturing is not possible without intelligent chips and related software, which belong to the hard- and soft-product categories. The scope of hard products is more than the scope of machinery; it has expanded to match the scope of electronic products and belongs to the category of equipment and products, as per the national classification.

It is suggested that financial support should be strengthened. The pilot demonstration of intelligent manufacturing must be organized and implemented. In addition, new-generation AI needs to be combined with equipment. Special funds should be transferred and increased to support the new generation of intelligent equipment and products. Further, the construction of an intelligent, basic-software tool set and sharing platform should be strengthened. Interface standards, specifications, and the integration of basic, intelligent software should be promoted to achieve a demonstration of the new applications and to popularize basic, intelligent software.

5.4 Formulate standard systems and alliances for the development of intelligent products and equipment

All the stakeholders in industry, universities, and research institutions should establish a sustained and stable cooperative relationship, at the strategic level, around the development, application, and promotion of intelligent products and equipment. In addition, they should carry out joint research, formulate technical standards, and share intellectual property rights based on the needs of intelligent product design and manufacturing. To explore various effective measures and ways to support the development of such an alliance, and to promote the establishment and improvement of a diffusion mechanism for the technological achievements of the alliance, the Ministry of Industry and Information Technology has put forward guidelines for intelligent manufacturing, implementing standardized projects, and promoting the construction of a standard system.

The construction of innovation capability and the development of innovation activities are unsustainable without a sound, perfect, and vibrant innovation system. The innovation system of intelligent products and equipment should undoubtedly take enterprises as the main body of innovation. However, institutions of higher learning and scientific research institutions should not only play a supporting role in this system, but also play their own unique role. Starting from the construction of a complete and effective technology supply chain, universities and research institutes belong to the source of this supply chain and should be greatly strengthened to avoid all kinds of institutions crowding the downstream of the technology supply chain. The research on common industrial technologies, which is very important for the sustainable development of technology and industrial machinery to create intelligent products and equipment, has been absent in the current innovation system; this lacuna must be filled from within the system. An industrial technology alliance should play a role in tackling the key problems of pre-competition technology, promote the formation of joint forces in some key technical fields, avoid duplication, and effectively utilize resources to achieve results as soon as possible. Alliance generalization and mass organization should be avoided to prevent the alliance from becoming a tool for national projects and state funding support. In the innovation system, there should be a large number of technical service organizations and functional design for the development of machinery for the manufacturing industry.

5.5 Promote the development of intelligent products and equipment based on the combination of production, teaching, and research

Enterprises are the main source of research for products and equipment, but they are not sufficient to achieve digitalization and intellectualization. Digital intelligentization relies on many frontiers of science and technology. The advantages, in this respect, lie with universities and institutes, rather than enterprises. Therefore, to accelerate the development of intelligent products and equipment for technology and industry, it is necessary to combine production, education, and research to promote the implementation of the common key technologies of intelligent products and equipment.

In determining the dominant status of the activities of industry, universities, and research institutions, we should follow the scientific evaluation method. Enterprises are the subject of demand and application, but they are not the subject of all the activities of industry, universities, and research institutions. Universities have the advantages of a talent pool and the ability to manage scientific research across production, teaching, and research organizations; thus, their unique function cannot be replaced. The orientation of the government should also follow the scientific evaluation method, and it should pay attention to the gap in investment from the basic research stage to that of production. Production and research activities driven by internal demand activate the vitality of the practice of innovation.

5.6 Establish a national demonstration base for typical applications of intelligent products and equipment

Digital networking and intellectualization are neither separated nor connected in series; rather, they are parallel. This kind of parallel relationship needs demonstration and experience summary. Domestic equipment, software, and systems urgently need to set up a demonstration base. Institutions should unite and do projects together. Through the application of a demonstration function, large, backbone enterprises can develop series software, integrated support platforms, and application modes for common intelligent product and equipment technology. Based on an integrated demonstration application, enterprises will be supported in the establishment of strategic alliances with partners, suppliers, and customers. They will be able to build complete, dynamic, and effective businesses in design and manufacturing, which will achieve industrial chain collaboration in terms of product development, production, procurement, sales, service, and global resource optimization in the value chain; this will allow intelligent technology to be widely used in products and equipment.

5.7 Speed up the building of a talent system for the design and manufacture of compound intelligent products

The key to achieving rapid development of the Chinese manufacturing industry, in terms of intelligent products and equipment, is its talent. Without the talent for excellent digital intelligent design and strong research teams, it is difficult to form an intelligent product and equipment industry. Considering the current talent gap in intelligent design and manufacturing in China, there is an urgent need to train and consolidate a large number of talented people in innovative, compound, and multi-level intelligent design and manufacturing to provide the necessary talent pool for the development of intelligent products and equipment. At present, there are too few people with skills in intelligent and digital manufacturing to meet the needs of Chinese enterprises; further, they need to be trained in more than one discipline. In the past, the education system was essentially a knowledge-based system for training in a single discipline. Now, however, enterprises need talent with multidisciplinary knowledge. The pace of teaching and scientific research has not kept up with the development of science and technology. At present, the most urgent problems to be solved are the need for multidisciplinary and interdisciplinary education and the further strengthening of personnel training systems.

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