DOI 10.15302/J-SSCAE-2022.04.001

Development Strategy of Smart Internet of Things System

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Abstract: The Internet of Things (IoT) is a critical component of modern digital infrastructure and is deeply integrated with fifth-generation mobile communication (5G), big data, cloud computing, artificial intelligence (AI), blockchain, and digital twins. It is profoundly changing the technology system, promoting the digital economy, and ushering in a new stage of smart IoT systems, in which everything is connected. This paper reviews the development status of the IoT in China, proposes the concept of a smart IoT system (IoT 2.0), and expounds on its implications, architecture, technical pedigree, and key enabling technologies. Practical cases of smart IoT systems are explored considering application scenarios including intelligent manufacturing, smart agriculture, smart grid, smart healthcare, intelligent transportation, and intelligent environmental protection, demonstrating the application value of the smart IoT system. Furthermore, we suggest implementation of a technology integration innovation project that integrates IoT, AI, 5G, and new application field technologies. This should focus on the research, development, and industrialization of intelligent products, such as smart IoT systems/cloud native platforms/low-code (no-code) application development environments and tool sets, high-end sensors for smart IoT systems, and IoT chips/special components. In addition, application demonstration of cloud-edge-end collaborative, autonomous controllable, safe, and credible smart IoT systems should be conducted.
Keywords: smart Internet of Things system; Internet of Things 2.0; architecture; technical pedigree; enabling technology; application scenarios

1 Introduction

With the accelerated pace of economic and social digital transformation and intelligent upgrading, the Internet of Things (IoT) has become an important part of modern infrastructure in the digital economy and a key driving force for the next stage of industrial revolution. This is of great significance for cultivating growth in the digital economy and supporting industrial transformation.

The concept of the IoT was formally proposed in the *ITU Internet Report 2005: The Internet of Things* issued by the International Telecommunication Union (ITU) in 2005. This study interprets the concept proposed as the IoT 1.0, and believe that the IoT connects everything in the world through ubiquitous networks, with the assistance of object recognition (e.g., radio frequency identification), sensing, embedded intelligence, and miniaturization technologies (e.g. nanostructures), thus to promote the development of the whole world by perceiving, understanding, and transforming the world. In recent years, developed countries have been actively researching the IoT-enabled technologies, digital technologies, and related industries. China also considers IoT development significantly important and this is promoted at a national strategic level. According to the *Outline of the 14th Five-*

Received date: March 16, 2022; **revised date**: May 8, 2022
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Funding program: CAE Advisory Project "Research on the Development Strategy of the New Internet Plus Action Plan under the New Era and New Situation" (2021-XZ-24)
Chinese version: Strategic Study of CAE 2022, 24 (4): 001–011
Cited item: Li Bohu et al. Development Strategy of Smart Internet of Things System. *Strategic Study of CAE*, https://doi.org/10.15302/J-SSCAE-2022.04.001

Year Plan (2021–2025) for National Economic and Social Development and the Long-Range Objectives Through the Year 2035, focus should be placed on the development of cloud computing, big data, IoT, industrial Internet, blockchain, artificial intelligence (AI), and virtual reality (VR)/augmented reality (AR). The *Three-Year Action Plan for New IoT Infrastructure Construction (2021–2023)* proposed that new IoT infrastructure would be initially built in major cities in China by 2023.

Currently, a new era has emerged where rapid development of intelligent information technology, emergency prevention and control of public health emergencies are intertwined, and we are encountering new situations involving strong international competition and multilateral cooperation. China has embarked on next stage development for comprehensively building a modern socialist country and a new development pattern of mutual promotion between domestic and international circulations. To adapt to such rapid dynamic change, we recommend that IoT development should also embark on a new development stage (i.e., IoT 2.0); implement a modern development concept of "innovation, coordination, green, openness, and sharing" [1–3]; and build a new development pattern that integrates innovation regarding technology, industry, application, talent, policy, and security systems.

The content of this paper is derived based on a consulting project from the Chinese Academy of Engineering "Research on the Development Strategy of the New Internet Plus Action Plan under the New Era and New Situation" [4]. This study focuses on establishing an in-depth understanding of IoT development in China. It proposes the concept, implications, system architecture, and technical system framework for smart IoT systems (IoT 2.0) adapted to the modern era, and summarizes common enabling and key application technologies in the implementation of smart IoT systems. Finally, we summarize application scenarios and smart IoT systems cases in representative fields.

2 Development status of IoT in China

2.1 Development trends of IoT industry

Significant breakthroughs have emerged in key core IoT technologies, especially in sensing, network, platform, and converged application technologies. For example, the technological engineering innovation of the new sensor network has reached the world's advanced level, the IoT Plus application development environment aiming at low-code/no-code has rapidly advanced, and key technologies and equipment of the transparent grid, including small and micro smart sensors and devices, have been widely used. Modern biotechnology, such as the integration of new IoT with gene editing and molecular design breeding, constitutes a key driving force for agricultural modernization. Autonomous and controllable Beidou high-precision navigation and positioning, and the fifth-generation mobile communications (5G) have advanced infrastructures to promote the integrated development of intelligent Internet and transportation.

Significant progress has been achieved in IoT-related industries. As an entry point for the integration of informatization and industrialization, the IoT has promoted the accelerated informatization, digitization, networking, and intelligence in multiple industries. With continuous penetration of IoT technology, application scenarios involving intelligent manufacturing, modern agriculture, smart grids, intelligent medicine, transportation, environmental protection, and other fields have been continuously expanded. This initially realized transformation from production to products and subsequently to services, changing production relations using technologies. Driven by demand in the application field, platform application systems and industrial clusters with exclusive field characteristics have been continuously formed. For example, industrial IoT platforms have been developed in the manufacturing field, and the national crop germplasm resource platform has been built in the agricultural field with germplasm resources and breeding requirements as the core. Additionally, the medical field has developed an industrial cluster centered on intelligent equipment, and remote/mobile medical care. In environmental protection, an environmental quality management system and a satellite remote sensing application system have been constructed, and breakthroughs have been achieved in the application of key technologies and equipment for transparent power grids.

The promotion and application of the industrial IoT platform in the manufacturing field has achieved remarkable results, and new models and formats of discrete and process-based intelligent manufacturing have emerged. In agriculture, IoT application scenarios have been developed for governments, research institutes, seed markets, and other subjects. In the medical field, 11 provincial-level demonstration zones involving IoT Plus Medical Health have been established, and the medical data sharing level has continued to improve, with the coverage rate of telemedicine counties (districts) reaching 90%. A national intelligent connected vehicle (Wuhan)

DOI 10.15302/J-SSCAE-2022.04.001

test demonstration zone was built in the transportation field. In the energy field, the Guangdong–Hong Kong–Macao Greater Bay Area electric power development plan and its application demonstration were completed. A multi-level, multi-angle, and all-weather (hourly) environmental monitoring application demonstration that features sky–air–ground integration has been established.

It should also be carefully recognized that core IoT technologies are controlled by other countries and this has not fundamentally changed. The supply and industrial chain coordination foundation is weak, the interconnection and interoperability of application fields are difficult, and data sharing and insufficient privacy protection remain problematic. Alongside the requirement to innovate the network development paradigm, breakthroughs are urgently required by platform architecture and system heterogeneous integration/optimization/intelligence, and the new application software development environments are not friendly enough. For example, adaptability of supply and market demand in the manufacturing field is low, the stability of the industrial and supply chains is encountering challenges, the constraints of resource and environmental factors are tightening, underlying driving technology development for the modern seed industry in the agricultural field is immature, and the commercial breeding platform has not yet achieved widespread adoption. The modern energy industry ecology that supports carbon peaking and carbon neutrality in the energy field is immature, and barriers exist between various entities in terms of information, technology, and industry management. Autonomy of the underlying software and hardware technology in the medical field, technical maturity of medical data processing, and clinical applicability of AI application technology must be further improved. Multi-source data sharing and service integration challenges in the energy field related to equipment intellectual property rights, regional coordination, and sustainable service energy operations, are more prominent. Innovative application of new technologies in smart environmental protection does not match the development requirements of the environmental protection business, and the technological research and development of environmental monitoring and intelligent governance facilities must be strengthened.

2.2 Development trends of IoT technologies

With continuous integration and rapid evolution of the IoT, AI, information and communication technology (ICT), and new potential technologies, the following trends can be discerned. (1) Interaction and data analysis requirements generated by massive connections promote and form a deeper integration of IoT and AI [5]. (2) The sensing technology including smart sensors as the core will be further developed. (3) IoT chips are developing toward high performance, high reliability, low power consumption and low cost. (4) Modules are being developed for customization and multiple functions. Narrowband IoT and 5G modules are expected to become new directions for future research. (5) Future network development will continue to focus on cellular communication and local area network technologies. The sixth-generation wireless network technology (i.e., WiFi 6, as a local area network to meet the requirements of a small area and high bandwidth) and 5G (large connection, high speed, oriented to a large area)/six-generation mobile communications are the focus of technological development. (6) New technologies under development, including metaverse technology, are expected to begin affecting new IoT technology development, raising the interface between users and the Internet from two-dimensional to three-dimensional, and the IoT upgrade will create new productivity.

3 Concept and architecture of smart IoT system

3.1 Concept of smart IoT system

The smart IoT concept (IoT 2.0) refers to a complex system that integrates human, information (cyber) space, and physical space. It intelligently interconnects new intelligent resources/capabilities/products and provides collaborative services under the guidance of a new development concept (innovation, coordination, green development, openness, and sharing) alongside the next-generation AI technology. The concept involves six new systems: product/capability/resources, network/perception, platforms, standards/security, applications, and user systems [3,6–9]. Among them, the next-generation AI technology includes data-driven deep reinforcement learning intelligence, network-based swarm intelligence, human–computer and brain–computer interaction technology-oriented hybrid intelligence, cross-media reasoning intelligence, and autonomous intelligent systems [10]. Wisdom of the system refers to the human-centered interconnectedness of human, information space, and physical space, and the progressive system of digitalization, instrumentation, service (cloud), collaboration, customization, flexibility, greening, and intelligence, under the guidance of modern development concepts and next-generation AI technologies.

The smart IoT system consists of new technologies, modes, formats, features, contents, and objectives, and facilitate transformation and upgrading of digitalization, networking, cloudification, and intelligence in application fields. (1) New technologies to be developed in this context are based on the new Internet, under the guidance of new development concepts and next-generation AI technology. This is aided by digital, networking, cloud-centric, and intelligent technology tools that are deeply integrated into eight categories of new technologies, including network, ICT, intelligent science, energy, material, biotechnology, green technology, and modern application field expertise. Intelligent connections are made between and people, machines, things, environment, and information in physical and cyber space, to provide on-demand services of smart resources, products, and capabilities anytime and anywhere. (2) The new model is user-centric, focuses on optimized integration of humans, machines, things, environment, and information, and conducts intelligent collaborative interconnection of digitalization, interconnection, cloudification, collaboration, customization, and flexibility. (3) This new business model is characterized by the intelligent connection of all things, intelligent guidance, digital/analog-driven, shared services, cross-border integration, and mass innovation. (4) The new features refers to that people, machines, objects, environments, and information autonomously and intelligently perceive, interconnect, collaborate, learn, analyze, cognize, make decisions, control, and implement entire systems and lifecycle activities. (5) The main aim here is to promote the integration and optimization of “six elements” (i.e., people, technology/equipment, management, data/model, material, and capital) and “six flows” (i.e., talent, technology, management, data/models, logistics, and capital flow throughout the entire system and lifecycle activities, and thus form digital, networked, cloud-based and intelligent products, equipment/systems, and full lifecycle activities. (6) The new goal is to support digital transformation and intelligent upgrading of current systems, and pursue innovation, green development, openness, sharing, and individuality.

3.2 Architecture of smart IoT system

The architecture of smart IoT system [3, 6–9] (Fig. 1) includes new smart resources/capabilities/product layer, new smart perception/access/communication layer, new smart edge processing platform layer, new smart system cloud service platform layer, new smart cloud service application layer, and new people/organizations. Each layer consists of new standards and safety management support.

The architecture of the smart IoT system is characterized by seven aspects. (1) New architecture for edge/cloud collaboration. (2) New information and communication technologies represented by cloud computing, AI, big data, Internet/modeling, and simulation/digital twins, are integrated with technologies in novel application fields. (3) Virtualization and servitization of the perception/access/communication layer uses cloud–network hyper convergence, network operating systems, and new network bearer structures to realize network virtualization, network control orchestration, software-defined network components, cloud network integration, and network security components to improve the utilization efficiency, safety, and reliability of heterogeneous network resources in IoT environments. (4) The model-driven, cloud-native new application development environment breaks through the concept of the traditional development environment, moving toward a modernized development environment supported by IoT technology, which is more suitable for application development in smart IoT scenarios. (5) Each layer has the connotations and contents of the new era, such as user-centered new intelligent resources, products, capabilities, and sharing services. (6) The IoT architecture has been intelligently expanded in various application fields. (7) Deep integration of the human, information space, and physical space through cross-application of the next generation of enabling professional technologies in various fields aims to build an intelligent application system with continuous optimization to achieve a harmonious ecology of human–machine symbiosis.

4 Technology pedigree and enabling key technologies of smart IoT system

4.1 Technology pedigree of smart IoT system

The technology pedigree of smart IoT system is divided into subsystems for the overall architecture, as well as support, software, security, standards, and application technologies [3,6,7]. (1) The overall architecture subsystem includes the overall, smart product, perception/access/communication layer, edge processing platform, cloud platform, and the smart IoT+ integrated applications technology systems. (2) The supporting technology subsystem includes new ICT, networking, intelligent, and application technologies. (3) The software technology subsystem includes system, platform and new application software technologies. (4) The safety technology subsystem focuses on protection technologies for physical, technical, management, and commercial safety. (5) The standards

DOI 10.15302/J-SSCAE-2022.04.001

technology subsystem includes basic/common, platform/support, key technology, product/service, and application standards. (6) The application technology subsystem includes the smart IoT application technologies in industrial, agricultural, energy, medical, transportation, and environmental protection fields.

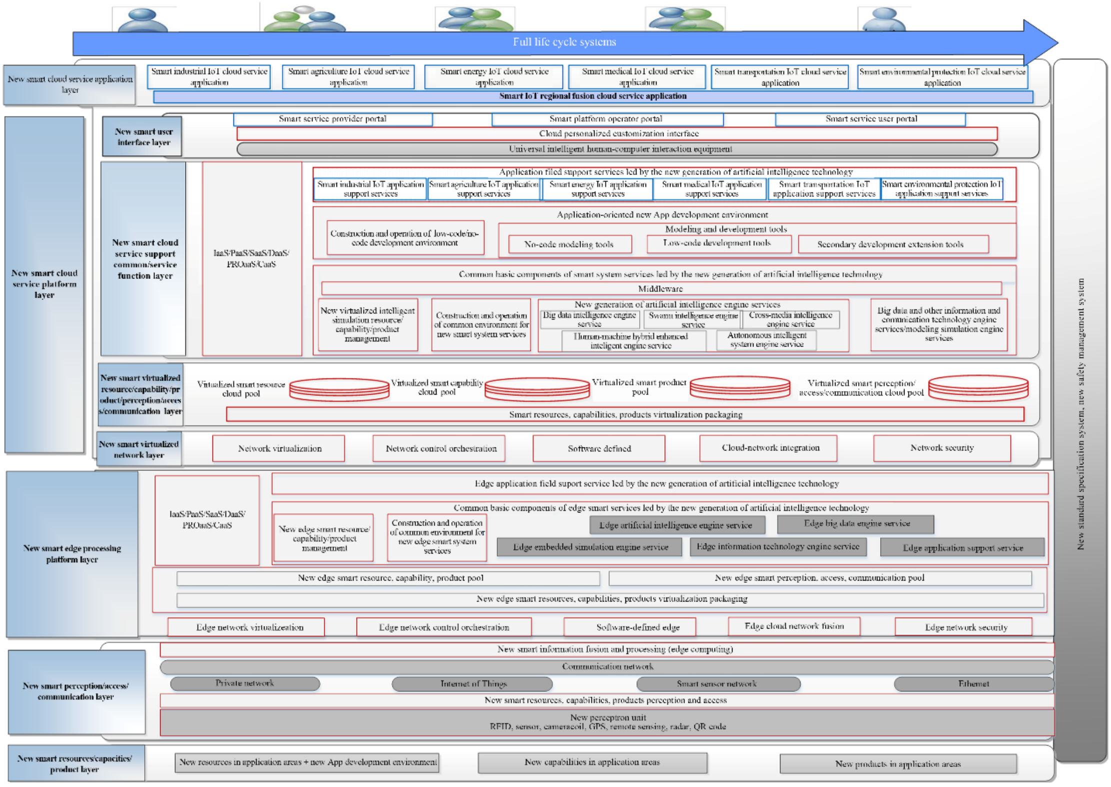

Fig. 1. Architecture of smart IoT system.

4.2 Key enabling technologies of smart IoT system

Smart IoT system key enabling technologies were classified into two categories: common and application, which cover six types of key application technologies formed by the deep integration of IoT and manufacturing, agriculture, energy, medical, transportation, environmental protection, and other fields of expertise. Enabling technology provides important support for the smart IoT technical spectrum and is considered a core element for realizing digital transformation and intelligent upgrading of traditional industries. Under the guidance of the new development concept and cross-application of the multidisciplinary integration of new technologies, in-depth development of smart IoT systems in various fields of technology, industry, and application is promoted.

4.2.1 Common key enabling technologies

Common key enabling technologies of smart IoT systems include 12 types [3,6–9], described as follows. (1) Sensing technologies provide the collection, processing, and identification of various forms of information. (2) Ubiquitous network technologies provide information transmission as required anytime anywhere. (3) Platform technologies provide decoupling, integration, and reconstruction for data, models, resources, and other elements. (4) Big data technologies provide precise, efficient, and intelligent technologies for the entire smart IoT systems lifecycle. (5) Cloud service technologies provide access, sharing, and collaboration of information, resources, and capabilities as well as smart computing. (6) AI technologies provide the intelligent perception, cognition, learning, analysis, integration, computing, monitoring, and processing of humans/machines/things/environment/information. (7) Edge computing technologies provide fast end-to-end computing. (8) High-performance computing technologies provide solutions to complex problems and large-scale intelligent collaboration. (9) System integration/optimization technologies provide an optimized integrated design. (10) Embedded modeling simulation and digital twin technologies provide model-based, efficient, intelligent development and operation. (11) Standards technologies provide standardization of technology and product coordination. (12) Security technologies focus on the provision of security-related enabling technologies in this context.

4.2.2 Key application technologies

The first category is key technologies for smart industrial IoT applications, dividing into industrial intelligence, AR, big data, and other industrial-related technologies. Among these, industrial intelligence enables innovative applications such as innovation in design mode, production intelligent decision-making, and optimized resource allocation [11,12]. Industrial AR converts information into visual content such as graphics, 3D animation, and videos. Industrial big data enables industrial systems to be equipped with patterns and results of intelligent functions, such as description, diagnosis, prediction, decision making, and control [13].

The second category includes key technologies for smart agriculture IoT applications, including life information sensor, phenotypic information acquisition, phenotypic data analysis, and database construction technologies alongside phenotypic big data management. Among these, life information sensor technology collects the information regarding seeds and their propagation/production environment, and obtains corresponding physiological and ecological information through signal transformation and AI data processing [14–17]. Phenotypic information acquisition technology automatically extracts important phenotypic features and logic from massive information relationships to achieve automatic accurate identification of phenotypic traits [18]. Phenotypic data analysis technology includes the entire process, from initial data acquisition to final refinement analysis. Big data management and database building are used to manage, store, and share phenotypic data.

The third category is key technologies for smart energy IoT applications, including power knowledge graph, terminal intelligent management and control platform, and transparent grid data platform technologies. According to the graph data structure, the power knowledge graph technology forms a large relational network of the object information of each power business [19]. Terminal intelligent control platform and transparent power grid data platform technologies refer to the provision of a perception function and massive multi-source heterogeneous big data assets for transparent power grids through intelligent terminals, and controlling the working status of same [20].

The fourth category is key technologies for smart medical IoT applications, including human physiological signs sensing, medical-oriented 5G, and personalized medical service technologies. The human physiological sign sensing technology comprehensively collects human physiological signals through sensing, which is used as the basis for clinical diagnosis and treatment [21]. Medical-oriented 5G technology is used for medical treatment. This realizes massive connections between people and things through 5G technology, and solves the limitations of traditional inefficient communication methods in the construction of smart medical services to improve efficiency [22]. Personalized medical service technology refers to IoT technologies related to human health, such as perceptual computing, personalized health management, and behavior recognition.

The fifth category involves key technologies for smart transportation IoT applications, including multisource collaborative high-precision positioning and perception, precise control of Beidou Plus 5G Internet of Vehicles (IoV), and intelligent high-precision map technologies. Themultisource collaborative high-precision positioning and sensing technology positively exploits the advantages of multiple information sources to achieve indoor–outdoor seamless positioning and navigation technology with excellent precision, availability, and continuity. IoV Beidou Plus 5G precise control technology provides high-level road perception, precise navigation, remote control, and other services. Intelligent high-precision map technology refers to key infrastructure for realizing auto-driving, which constitutes the carrier of real-time perception of traffic resources in all times and spaces, and is the basis of the entire process operation and control of vehicles [23,24].

The sixth category involves key technologies for intelligent environmental protection IoT applications, including environmental big data, intelligent early warning environmental big data mining and analysis, and multi-mode super-set simulation technologies in the context of environmental systems. Among these, environmental big data technology is oriented to the application service requirements of environmental protection and management decision-making, and conducts efficient and orderly organization, management, and application of ecological environmental data resources. Intelligent early warning environmental big data technology plays a role in air condition prediction, environmental carrying capacity monitoring, and assessment by establishing a scientific event model through data mining [25]. Multi-mode super-set simulation technology for environmental systems refers to the integration and comprehensive application of single and composite model and analysis technology in environmental simulation, strengthening the integration of environmental models and geographic information system (GIS) applications.

DOI 10.15302/J-SSCAE-2022.04.001

5 Typical application scenarios and practical cases of smart IoT system

5.1 Representative application scenarios and practices of smart industrial IoT system

5.1.1 Application scenarios

The representative application scenarios of smart industrial IoT include the following: (1) In R&D and design stages, 5G, IoT, and AR/VR technologies are utilized to collect real-time images and data from experimental sites and generate digital models of industrial components, equipment, systems, and environments. This helps to realize a trans-regional online joint approach to solving various problems, including remote collaborative designs. (2) In the manufacturing stage, multidimensional real-time monitoring is realized based on a digital twin system and industrial IoT technology. The virtual-real mapping method is used to perform active perception, dynamic optimization and control, and intelligent decision-making for flexible manufacturing systems. (3) In the sales and service stages, various forecasting functions are realized, and relevant sales strategies are formulated by establishing high-precision prediction models based on AI technology.

5.1.2 Practical cases

A case involving 5G enabling intelligent manufacturing in a factory to realize remote monitoring of production equipment is shown in Fig. 2. The production tasks in the original factory were frequently adjusted according to the production line, and the network had disadvantages such as multiple mobile devices, complicated wiring, lengthy construction period, and difficult point inspection, and challenges such as significant delay, instability, flashing among other issues. In the case where a factory is transformed with 5G technology, the fast and stable collection, return, and analysis of data such as industrial production operation status is realized, and the entire process is digitized through a simulated production system; the workshop equipment networking rate exceeds 85%, and the equipment operation and maintenance efficiency is increased by over 25%.

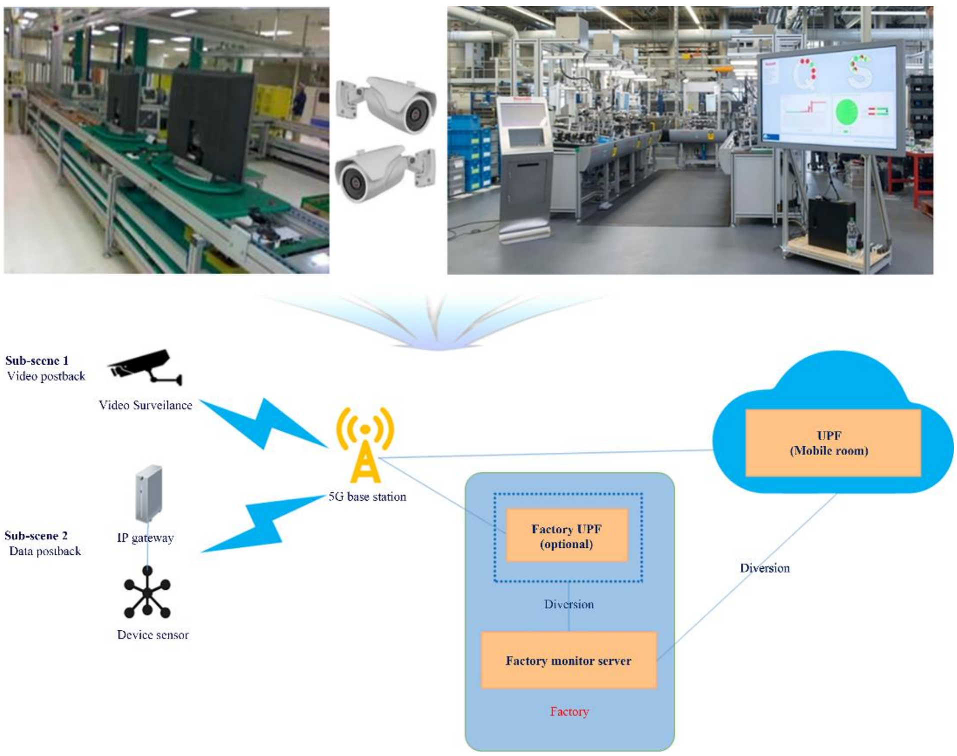

Fig. 2. Schematic diagram of remote monitoring of production equipment enabled by 5G in intelligent manufacturing of a factory.
Note: IP refers to internet protocol; UPF refers to user plane function.

Another case has realized intelligent supply chain management and control based on blockchain. With the COVID-19 outbreak, governments and enterprises urgently require transparent, safe, and traceable information regarding epidemic prevention materials. A company developed a trusted traceability system for anti-epidemic materials using the blockchain technology, which provided functions such as visual display of anti-epidemic materials on the chain, audit and labeling of supply and demand information, and timely and reliable data of anti-epidemic materials for enterprises and management departments. This solution was subsequently well received.

5.2 Representative application scenarios and practices of smart agriculture IoT system

5.2.1 Application scenarios

The representative application scenarios of the smart agriculture IoT system include the following: (1) The seed industry supervision scenario for the management department, which includes seed industry data and realizes the traceability of varieties, seed quality, market subjects, one-stop information inquiry, and business processing. (2) The germplasm resource management scenario is oriented toward scientific research institutions. This is used for the digital management and utilization of crop germplasm resources and genetic materials and to support the storage of breeding resources and the selection and breeding of excellent varieties. (3) Commercial breeding scenarios for breeding companies. Through the construction of various functional modules, the standardization, programming, and digitalization of the breeding process can be realized, and functions such as the efficiency of breeding selection and scientific analysis of breeding data are provided. (4) The IoT scenario for the seed industry breeding/propagation base adopts a sensor network, video surveillance, mobile communication, and other information technologies, as well as the crop phenotype observation technology, to achieve quality and efficiency improvement of seed production and propagation. This is achieved by automation, digitalization, and intelligence technologies spanning the entire process. (5) The market-oriented seed industry socialization service scenario provides access to the information flow for the seed and other agricultural materials industry, provides financing and trading services based on electronic trading information systems, and finally realizes the socialization service of the seed industry.

5.2.2 Practical cases

The crop germplasm resource database is one application for the national crop germplasm resource platform. The types of services provided on relevant platforms include crop germplasm information release, data-sharing services, science popularization publicity, among other service types. Once the crop germplasm resource database is established, information sharing of 200 crops and 4.1×10^5 germplasms can be realized. This provides inquiry and reference services for scientific research in fields such as the national crop germplasm resources, breeding, cultivation, and plant protection including technical and data support services for more than 50 national science and technology projects.

Another case involves an integrated commercial breeding cloud platform called the Golden Seed Breeding Cloud Platform. This supports the strategic adjustment of agricultural structure and improves the precision and informatization level in the agricultural industry. It also integrates computers, GIS, AI, and other technologies; supports big data integration and innovation, IoT, traditional breeding technologies, and provides information-based solutions for commercial breeding, such as trait data collection systems and two-dimensional barcode germplasm resource management systems.

5.3 Representative application scenarios and practices of smart energy IoT system

5.3.1 Application scenarios

One representative scenario for smart energy IoT is the transparent power grid system. A transparent power grid uses data at its core to realize visible, knowable, controllable, and arbitrary state transparency of the power system. Digital technologies such as cloud computing, big data, IoT, mobile Internet, AI, and blockchain are applied to digitally transform the traditional power grid, occupy the role of data as production factors, and optimize energy and business flows guided by the data flow.

5.3.2 Practical cases

In the Guangdong–Hong Kong–Macao Greater Bay Area, the intelligent operation and maintenance process of the transparent power grid widely adopted micro smart and wireless sensors to collect power grid data, while benefiting from the characteristics of miniaturization, intelligence, low power consumption, self-capture, self-organized networks, and high precision and reliability of micro smart sensors, to realize comprehensive, timely, and reliable perception of power grid information. A large-scale sensor network was built to monitor power grid equipment in real time and measure wide-area big data of large power grids. Micro intelligent sensor controllers, 5G and other communication technologies have been used to realize the engineering application of edge computing and adaptive control algorithms. Combined with AI algorithms such as machine learning, this can

DOI 10.15302/J-SSCAE-2022.04.001

quickly summarize, analyze, and process massive data, realize online real-time intelligent perception of equipment health and environmental status, support efficient fault diagnosis development, operation and maintenance decisions, and improve power system operation reliability.

5.4 Representative application scenarios and practices of smart medical IoT system

5.4.1 Application scenarios

Four representative application scenarios can be described regarding smart medical IoT. (1) The smart clinical scenario uses 5G, IoT, and other technologies, to achieve bedside intelligent interaction of ordinary smart wards, expert remote real-time diagnosis, treatment, and other functions. (2) Smart medical service scenarios include hospital systems that should be built based on 5G, IoT, and other technologies to support the realization of patient self-service medical care, to improve hospital service levels and management efficiency. (3) The health management scenario, which is based on AI, IoT, and other technologies, is used for comprehensive chronic disease management, and disease screening is conducted in the community to achieve disease prevention. (4) Smart hospital management scenarios enhance the capacity of smart hospital and material logistics and medical waste management.

5.4.2 Practical cases

This case involves 5G remote treatment. During COVID-19 prevention and control, with the aid of 5G technologies that feature high reliability and low delay, remote experts or medical teams could achieve the following objectives: remote control of medical diagnosis and treatment equipment, receiving treatment site images, remote consultation, and on-site medical staff guidance for diagnosis, treatment, or surgery. Experts geographically based in a remote ultrasound medical center (e.g. a hospital) use the 5G network to remotely control an ultrasound robot in a remote hospital through a handle to perform ultrasound examination and treatment.

The practical case for a smart pension platform includes developing a digital smart elderly care service platform to collect elderly-related data in civil affairs, health care, public security, and finance, etc., to improve databases for elderly care facilities, service organizations and other related data. This also involves digital management of basic services, such as the assessment of elderly service requirements, provision and feedback tracking, management of elderly care institutions, and elderly visitation.

5.5 Representative application scenarios and practices of smart transportation IoT system

5.5.1 Application scenarios

The representative application scenarios of intelligent transportation IoT can be described as follows. (1) Using the IoT, an intelligent road scenario could be implemented through cloud computing, big data, AI, and other information technologies. A smart carrier for the collection and release of urban traffic information centered on data is constructed to realize automatic perception and identification of road traffic operation situations, to provide technical support for intelligent vehicles to realize vehicle-road collaboration, and to create a safe, efficient, and comfortable travel environment and services. (2) The intelligently connected vehicle scenario includes advanced sensors, information and communication, the Internet, cloud computing, and other technologies, whereby the autonomous driving function will gradually be realized, creating a new product, mode, and ecology that integrates autonomous driving and connected vehicles.

5.5.2 Practical cases

In the vehicle–road coordination system, the intelligent roadside case provides functions such as dangerous driving and road abnormality reminders, vehicle violation warnings, congestion analysis, intersections, coordinated scheduling, and other functions, using intelligent sensor equipment and the combination of intelligent onboard information. Beidou Plus 5G empowers an autonomous driving infrastructure with independent core technologies and algorithms, providing all-weather, all-day, high-precision positioning, navigation, and timing services for test roads to improve the level of integrated development of autonomous driving and smart cities.

For intelligently connected vehicles, in future, the application scenario of intelligent high-precision maps must involve the integration of vehicles and roads with the support of collaborative sensing and precise positioning technology (Fig. 3). With the support of Beidou Plus 5G ground- or satellite-based enhancement, technologies such as high-precision maps and inertial navigation are superimposed to meet the requirements for intelligent networked vehicles, in achieving centimeter-level position, nanosecond-level precise perception, and multi-level precise coordinated control of position and time in complex scenarios such as signal occlusion.

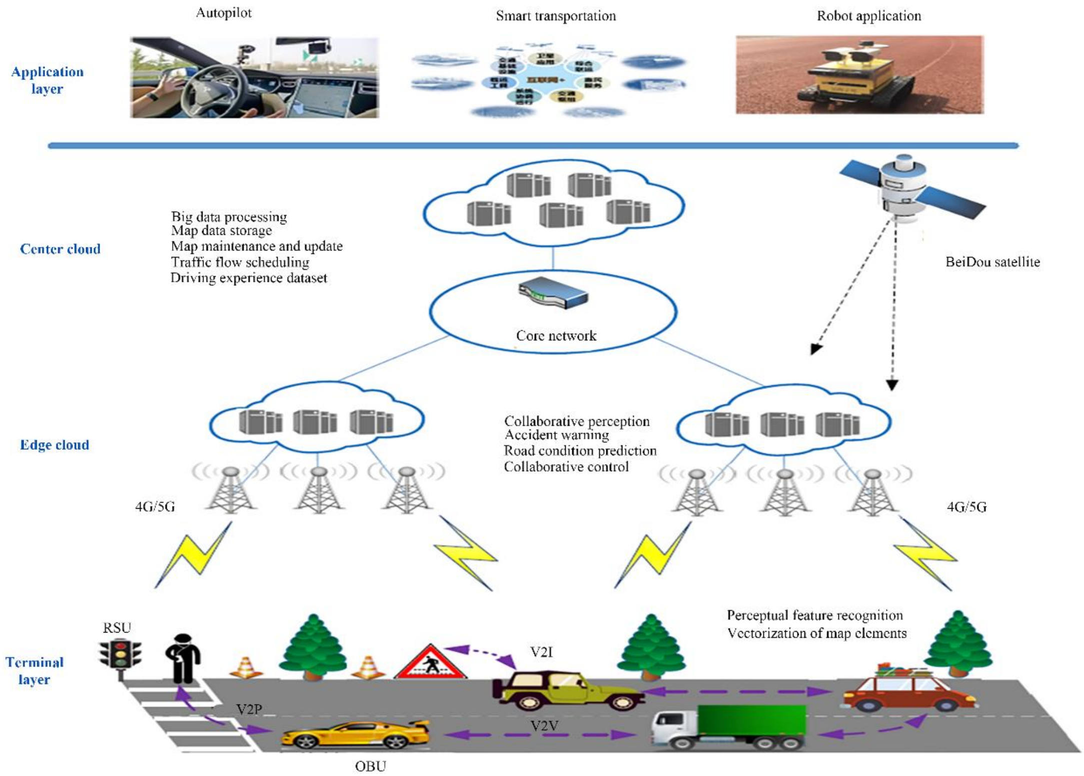

Fig. 3. Schematic diagram of intelligent connected vehicle.

Note: 4G refers to the fourth-generation communications; RSU refers to road-side unit; V2I refers to vehicle–infrastructure interconnection; V2V refers to vehicle–vehicle interconnection; V2P refers to vehicle–pedestrian interconnection; OBU refers to onboard unit.

5.6 Representative application scenarios and practices of smart environmental protection IoT system

5.6.1 Application scenarios

Three representative application scenarios for smart environmental protection IoT can be described. (1) The space–air–ground integrated stereo monitoring system obtains all types of data resources for atmospheric environment monitoring. (2) Water environment monitoring can be achieved based on the basin control unit, a stereoscopic and refined watershed unit monitoring function is established by obtaining the data from monitoring methods including satellite remote sensing, unmanned ships, and monitoring sub-stations (3) A precise stereoscopic monitoring system for haze control can be used. This involves satellite remote sensing, high-altitude video, drones, and other technologies, which are integrated to comprehensively collect air quality and pollution source data. Through environmental big data and multi-model analysis, pollution emission trends can be quickly diagnosed to support dynamic air quality regulation.

5.6.2 Practical cases

An urban air pollution grid intelligent monitoring and supervision platform was established to integrate diversified monitoring data regarding meteorology, pollution sources, various stations (micro, municipal control, provincial control, and national control stations), radars, aerial vehicles, unmanned aerial vehicles, handheld devices, and video devices, to achieve multi-channel data fusion and linkage analysis. An integrated atmospheric hotspot monitoring system could be built for space, ground, and air to accurately reflect changes in air pollution in the area and combine early warning, forecasting, and reporting mechanisms to form grid-based management and control of polluted areas.

An urban stereo monitoring and big data platform is established where a technical system could be developed for secondary pollution coordinated prevention and control that integrates accurate forecast, accurate analysis, precise policy implementation, and fine assessment, and pollution could be accurately forecast through an online monitoring and early warning network. Rapid identification and quantitative analysis technologies were used to identify pollution types, hotspots, and causes. Precise policies are implemented based on dynamic total quantity

DOI 10.15302/J-SSCAE-2022.04.001

accounting and related identification technologies, and a fine assessment is implemented based on dynamic aggregate accounting and supervision technology.

6 Suggestions for smart IoT system development

To adapt to the new era, IoT development is moving from stage 1.0 to 2.0, that is, the smart IoT system. As a critical component of the new digital infrastructure, smart IoT should be deeply integrated with technologies such as 5G, big data, cloud computing, AI, blockchain, and digital twins to maintain and advance the rapid evolution of potential capabilities. This will significantly promote the digital economy development. On one hand, New integrated technologies enable and drive digital transformation and intelligent upgrading of production, operation, and enterprise management systems, and support the digitalization, networking, and intelligence of the core business, such as product innovation and user service, to significantly improve enterprise market competitiveness. On the other hand, the smart IoT system provides new technologies, products, services, and infrastructure for smart IoT, forming a class of strategic emerging industries adapted to the new era and significantly promoting economic and social development.

Driven by demand and innovative technology, models, technologies and ecosystems of smart IoT systems will continue to develop. (1) Attention should be paid to the construction of a technological innovation system that integrates government, industry, universities, research institutes, finance, and application, and interdisciplinary collaboration mechanisms should be strengthened to form a coordinated ecosystem. (2) It is suggested that further attention should focus on training interdisciplinary professionals in various fields, especially those who integrate the expertise of IoT technology, ICT, and application. (3) The construction of digital infrastructure requires further attention, this includes modern IoT infrastructure at global, national, and local levels. (4) Focus on global, national, and local policies and resource support is also recommended. (5) Attention should be paid to the coordinated development of technology, applications, and industry as follows.

In terms of technical research, the focus of attention should turn to the following seven aspects. (1) The leading role of the next-generation AI technology should be focused. The deep integration of ICT (represented by 5G, next-generation AI, cloud computing, big data, blockchain, digital twin, and modern modeling and simulation) and professional technologies in new application fields is suggested. This effort will drive continuous innovation of the technical aspects of smart IoT systems. (2) Importance should be attached to the development of key core technologies such as intelligent sensing, future network, and new communication technologies. (3) It is also necessary to research new models, processes, technological means, and ecosystems in smart IoT applications, which address all stages involving full lifecycle activities in related application fields. (4) Focus should be placed on research and construction of the basic capabilities in IoT applications, such as databases, algorithm libraries, model libraries, platforms, and computing capabilities. (5) Further research is required on smart IoT business modes, and (6) security technologies and evaluation systems. (7) Future technological and ecological development is also pertinent, especially the integration of rapidly developing metaverse concepts and related technologies [26,27]. This will drive many fields to reduce costs, improve efficiency, and maintain green and flexible characteristics in full lifecycle activities, and strengthen the digital twin capabilities of smart IoT systems.

In terms of industrial development, the following five aspects should be strengthened. (1) Products such as cloud-native platforms, low-code/no-code application development environments and tool sets should be developed, focusing on improving embedded industrial software, integrated development environments, and integrated industrial software platforms for segmented industries, to attract more enterprises to build a service-oriented ecosystem. (2) The development of smart products should be reinforced including high-end sensors, IoT chips, and embedded IoT operating systems to promote evolution of the IoT industry ecosystem such that high-end, localized network controllers and operating systems can be developed, and to promote the localization and white-box of network equipment. (3) Construction of a series of national data platforms represented by health and medical data platforms and technology-sharing platforms should be supported based on privacy and distributed ubiquitous computing to form security, trustworthiness, and privacy protection capabilities of data assets and elements. (4) Knowledge transformation into software, open-source architecture, and cloud-based software should be strengthened to form an independent and controllable new IoT Plus development environment and application ecology. (5) Strengthening the development of metaverse-related industries is also recommended

It is necessary to improve smart IoT application practice based on five aspects. (1) The characteristics of industries and enterprises should be highlighted. (2) Model, technology, and ecosystem reforms that are problem-solving and value-oriented should be highlighted. (3) The comprehensive optimization and intelligentization of the "six elements" and "six flows" of the smart IoT system should be highlighted. (4) The philosophy of systems engineering should serve as the principle of implementation. (5) Various application demonstrations should be conducted. For example, a cloud–edge collaborative application platform can be built to construct an autonomous and controllable open-source embedded operating system with good versatility for application fields, joint application of network and AR/VR, 4K/8K services, industrial chain collaborative R&D applications based on independent controllable development environments, metaverse-related applications, among others.

Acknowledgments

We would like to thank the following academics and experts for their support and contribution to this research: Chen Zuoning, Li Licheng, Li Lanjuan, Liu Jingnan, Liu Wenqing, Liu Yunjie, Sun Jiaguang, Sun Jiulin, Zhao Chunjiang, Ma Chen, Liu Jiang, Liu Yingbo, Yang Lin, Li Yingying, Li Tan, Yang Jingwen, Chen Qianyu, Lin Tingyu, Hou Baocun, Gao Kefu, Cai Zexiang, and Wei Wei.

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