Chapter 1
Introduction of Agricultural IoT

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Abstract Agricultural IoT (Ag IoT), a term that refers to applications of IoT technology in agricultural production chain, brings together sensing, computing, and implementing devices to support need-specific operations, so that farmers can properly and promptly respond to the situation for improving yield and income. The adoption of Ag IoT can help farmers update their production from often low-efficiency traditional mode to a digital farming that is supported by demand-specific and time-sensitive production information. It can facilitate the expansion of farming management from in-production only to include both ends of pro-production and post-production so as to cover the entire operation chain, thus transforming agriculture from the productivity-driven business model to a market-driven model for best returns. This chapter lays an introduction of IoT technology, covering its origin, concept, and development status, followed by an elucidation of its architecture, features, and specific applications.

Keywords Internet of Things · Agricultural production chain · Digital farming · Field information · Need-specific operations

1.1 The Development of IoT

IoT stands for "Internet of Things," and the initial application of IoT technology could be dated back to the first US-Iraq war in 1991. As the war came to an end, the US military discovered that a large amount of supplies and containers were accumulated in different ports and airports. When dealing with post-war supplies, they encountered difficulties in getting prompt information of where exactly those items should be shipped and which department should manage them. Numerous

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human and financial resources were exhausted to acquire the accurate ownership status of those supplies. To solve the problem, the United States Department of Defense launched a project named Visual Management of Military Supplies, which adopted RFID technology for the intelligent identification and management of military supplies.

Learning from military successes, some US companies have begun to adopt this mighty technology for civilian uses. For example, UPS, FedEx, and other large logistic companies have adopted RFID technology to create shipment tracking systems that allow quick track and query of the shipments, leading to sound service evaluations. In the early application of IoT technology, its application mode manifested as an active interaction between human and "things," which laid the foundation for the development of IoT technology.

With the rapid development and integration of sensing, communication, and computing technologies, physical properties and spatial-temporal characteristics of the "things" became easier to obtain and process in real time. Information exchange between "things" gradually became realizable through data networking and communication technologies.

The concept of IoT was originally from Bill Gates' book (Gates et al. 1995) titled *The Road Ahead* but did not capture much attention at the time, probably due to the limitations of contemporary wireless network and sensing technologies. In 1999, the then Executive Director of Auto-ID Labs at MIT, Kevin Ashton, first formally introduced the concept of "Internet of Things" in his one speech (Foote 2016). Then in 2005, the International Telecommunication Union (ITU) further elaborated on the definition of IoT in its report titled *ITU Internet Reports 2005: The Internet of Things* and expanded IoT to include communication systems that connect humans and "things" or "things" and "things" in an Internet-enabled environment (Zhong 2012; Wang et al. 2016).

1.2 The Concept and Connotation of IoT

1.2.1 The Concept of IoT

Aforementioned, IoT was developed based on the Internet. Like the Internet, IoT uses communication networks as the medium, but unlike the Internet, it enables the interconnection between human/things and things. What is implied is that in IoT, the scope of client has been expanded to include any object. Briefly, IoT aims to connect all kinds of items via the Internet for perceiving, delivering, and sharing information. Through exchange of information, the world can evolve into a state where "all things can be connected." In short, IoT provides a handy tool for achieving intelligent monitoring and management for many applications.

IoT can connect ubiquitous end-devices, including those with "intrinsic intelligence," including sensors, mobile terminals, control systems in buildings, and household intelligence and video surveillance systems, and those with "external intelligence," covering RFID-attached assets and human or equipment with wireless terminals. These items can be interconnected, integrated, and remotely operated relying on various wireless or wired communication networks connected under IoT domains. Supported by appropriate information security guarantee mechanisms, IoT can provide safe, controllable, and personalized real-time online monitoring, tracing, alarming, scheduling, planning, remote controlling, decision supporting, and many more management and service functions. It also provides the base for integrating "monitor, management, and control" of "all things" in a high-efficiency, energy-saving, and safe environment.

1.2.2 The Connotation of IoT

Though IoT is built on the Internet, it goes beyond the scope of the Internet. One way to gain a comprehensive understanding of IoT technology is to compare its concept with that of the Internet.

First, it should be noted that IoT is not merely a new communication network; instead, it taps into the long-existing network communication technology and expands on that basis. As the Internet is a huge public communication network that accommodates almost all communication networks, IoT is just one of such communication networks built on the Internet for connecting "things" to exchange information with little or no human intervention in managing such exchanges. Physically, IoT interconnects those "things" using either wired or wireless or hybrid telecommunication networks to accommodate data tele-collection and dissemination (Zhang and Ehsani 2006).

As a huge global network woven by computing networks among human, the Internet provides a platform for information exchange among users. In comparison, IoT can connect "things" other than human, such as sensors, controllers, and even animals, plants, soil, and equipment to the Internet. Therefore, IoT is an extension of the Internet, an extension that includes non-human users. Sensors, controllers, and wired/wireless data communication networks are the essential elements for such extended capabilities.

From a broad perspective, with the rapid development of sensing, communication, and information technologies, future Internet, or the next generation of Internet, can connect human and "things" in a ubiquitous network via wearable devices. We can be interacting with others or "things" around us anytime and anywhere without even noticing it. In fact, although their names are different, there is no essential difference between IoT and the next-generation Internet. Both can interconnect humans via appropriate communication devices anytime and anywhere through any network to seamlessly exchange needed information with any person or device.

Defined narrowly, a communication network belongs to the category of IoT as long as it can interactively connect "things" via a data communication network, whether connected to the Internet or not. Other than exchange information between "things," an IoT can also seamlessly integrate existing public communication network to accommodate information exchange between human and "things" and form a ubiquitous network supporting smart world.

Although IoT is closely related to the Internet, they are also relatively independent networks. In an IoT, different systems and/or application terminals can co-exist in an interactive manner to support automated or remote perception and/or control functions. For different applications, the systems can be completely different: some may not share information with other systems, but some may engage in massive interactive data exchanges with other systems. Therefore, IoT, customarily, can be deemed as a collection of "ubiquitous network," which may or may not connect directly to each other, used in automated or remote monitoring, managing, or control applications. From this point of view, IoT and the Internet differ.

1.3 Development History and Present Situation of IoT

1.3.1 Development History of IoT

One of the first examples of using IoT-like technologies dated back to the early 1980s on a Coca-Cola machine located at the Carnegie Mellon University. Local programmers connected sensing devices to the refrigerated appliance via the Internet to see if there was a drink available, and if it was cold, before making the trip to get one (Veneri and Capasso 2018). The phrase "Internet of Things" as a concept was first formally introduced by Kevin Ashton, the then Executive Director of Auto-ID Labs at MIT, in his one speech at Procter & Gamble in 1999 (Foote 2016). In this speech, Ashton described a novel idea of using sensors (e.g., radio-frequency identification, RFID) to "tag" things, and it would involve the use of computers for the management, tracking, and inventory of those "tagged" things.

Since the concept of IoT was proposed, the general public have begun to notice applications related to IoT technology. On November 17, 2005, the International Telecommunication Union (ITU) released the *ITU Internet Report 2005* and formally proposed the concept of IoT at the World Summit on the Information Society (WSIS) in Tunisia (Zhong 2012; Wang et al. 2016). The report stated that the ubiquitous IoT Communication Age is coming and all objects in the world can actively exchange information through the Internet. RFID, wireless sensor networks (WSN), nanotechnology, and smart embedded technologies will be adopted more extensively. Countries around the world have also kick-started a wave of IoT development. For example, the United States, the European Union, Japan, South Korea, Australia, Singapore, and many other countries and organizations have successively launched research programs on IoT technologies for various applications. Those IoT applications would allow users to enjoy intelligent operation through intelligent processing (Liu and Zhou 2012). In an outlook report titled *Internet of Things in 2020: A Roadmap for the Future* published in 2008, the

European Union has pointed out that after 2020, EU countries are expected to form ubiquitous networks that integrate humans, machines, and "things" (Hai 2012).

1.3.2 Development Strategies of IoT in Various Countries

"Smart Planet" in the United States

The development of IoT technology and applications in the United States follows a clear "bottom-up" trajectory. In the early 1990s, the United States Department of Defense (DoD) regarded wireless sensor network (WSN) as a major field of research and created a number of related programs. The National Science Foundation (NSF) of the United States also developed WSN research programs that aimed to conduct systematic research on the basic theory of sensor networks. Constructing sensor subnet on next-generation Internet counts as a critical research topic. In addition, many manufacturers, such as Analog Devices, Freescale Semiconductor, and Ember Technologies, developed and commercialized various demand-specific IoT platforms or products.

In 2008, IBM proposed the concept of "Smarter Planet" with the strategic core of "cloud computing + Internet." After Barack Hussein Obama was elected as the President of the United States, he publicly endorsed this strategy (Bei 2017; Wu 2016). Under this strategy, the next step of IoT development is to fully adopt this novel intelligent information and network communication technology across the board. For example, the embedded or assembled sensors and other devices would be integrated into railways, highways, power grids, buildings, and bridges, giving rise to a state of interconnection among those objects. Then supercomputers and cloud computing would be used to process and analyze the acquired data from those objects to monitor their conditions, so as to realize the information exchange between the physical world and the computer for the eventual foal of seamless connection between "things" and "things" in IoT platforms. Since then, IoT has become increasingly widespread in all aspects of life in the United States.

In order to fully realize the potential of all the economic, social, and innovative benefits the IoT can deliver, and to achieve the widespread utilization of the IoT, in June 2016, Intel, Samsung, and the Information Technology Industry Council (ITI) launched the National IoT Strategy Dialogue (NISD), an initiative that brought together industry and organizational partners to jointly create strategic recommendations on IoT technologies to US policymakers (Zhang 2016). The US federal government actively responded to such endeavors. On January 8, 2020, the House of Representatives passed a resolution H.Res.575 proposed by Representative Bill Flores (R-TX) which stated that all stakeholders in the deployment of 5G communications infrastructure should carefully consider adherence to the recommendations of *The Prague Proposals*.

"IoT Action Plan of EU" for the European Union

The European Union (EU) has also made great efforts to scale up the applications and economic benefits of IoT. In June 2009, the EU Commission released a plan titled *Internet of Things – An action plan for Europe*, which acknowledged the opportunity of IoT, outlined its governance, and formulated 14 specific action lines (Song 2017). In September 2009, the European Research Cluster on the Internet of Things (IERC) issued *Internet of Things Strategic Research Roadmap*, which incorporated a common definition of the Internet of Things (IoT); provided the vision of "people and things to be connected anytime, anyplace, with anything and anyone, ideally using any path/network and any service"; and declared 17 IoT application domains, including food traceability, agriculture, and breeding (Dong 2012). Many European countries have created their specific plans for achieving the goal. For example, the Finnish Strategic Center for Science, Technology, and Innovation: For Information and Communications (ICT) Services, businesses, and technologies released a research agenda "Internet of Things Strategic Research Agenda (IoT-SRA)", specifying IoT research mission, targets, research themes, and applications for Finland (Ailisto et al. 2011; Dong 2012).

At present, the EU has made breakthroughs on IoT applications in small-scale farming, precision livestock farming, and intelligent fisheries. Among those, greenhouse IoT in the Netherlands is highly developed, taking the leading position in terms of intelligent management and environmental control of greenhouse. According to *Internet of Things in 2020: A Roadmap for the Future*, it was expected that EU countries will make any object intelligent and form a ubiquitous network connecting human beings, machines, and "things" after 2020 (Hai 2012).

"u" Strategy in Japan and South Korea

Adhering to its strategy of establishing "the world's most advanced IT nation," Japan was one of the leading countries with regard to launching IoT applications. The Japanese approach of IoT development went through four stages of e-Japan, e-Japan II, u-Japan, and i-Japan. The e-Japan strategy was issued by the Japanese IT Strategy Headquarters in January 2001 which was mainly focused on constructing broadband infrastructure for the nation (Zhou 2012). It included the declaration of four priority policy areas of (1) establishing the ultra-high-speed network infrastructure; (2) facilitation of e-commerce; (3) realization of e-government; and (4) nurturing high-quality human resources. Since the e-Japan I strategy was completed ahead of schedule, the Japanese government launched an e-Japan strategy II in July 2003, which was the blueprint of the second phase development of "advanced IT nation" (Zhou 2012). The second phase strategy shifted its focus from "IT infrastructure development" in the previous phase to "effective IT utilization" by identifying seven leading areas in promoting such utilization, including medical services, food, lifestyle, small and medium enterprises financing, knowledge, employment and labor, and public service. In 2004, the Ministry of Internal Affairs and Communications (MIC) of Japan formally announced the u-Japan Policy, which provided guidelines for the creation of a seamless and ubiquitous network in which people can receive services without noticing the existence of the networks (wired or wireless). This Policy aimed at stimulating efforts to build Japan into a country that anyone and anything can be connected at anytime and anywhere before 2010 (Zhou 2012). After the global financial crisis, Japan's IT Strategy Department released a medium- and long-term development strategy of IT technology, *i-Japan strategy 2015*, in July 2009 as the strategy to achieve quick economic recovery. This strategy aimed to improve Japan's global competitiveness by building a digital Japan. In recent years, the Japanese government has shifted its development focus to intelligent cloud, promoting the integration and sharing of massive information and knowledge in the Japanese social system with the help of cloud services.

Similar to Japan, South Korea has also incorporated IoT into its national IT development plans at a very early stage. For example, the *Cyber Korea 21 Initiative* released in 1997 was focused on the popularization of the Internet (He 2004). Since then, from the deployment of RFID, cloud computing promotion, to other relevant technological breakthroughs, the South Korean government has successively issued many national informatization construction plans. Among them, the u-Korea strategy was one of the major strategies aimed at the popularization and application of IoT in South Korea. Started in March 2004 by its Ministry of Information and Communication Industry, South Korea established a u-Korea strategic planning group which set up a 10-year u-Korea strategy. According to that plan, the development period of u-Korea is 2006–2010, and the maturity period is 2011–2015. Based on the best ubiquitous WSN in the world, this strategy intended to make all resources in South Korea digitized, networked, visualized, and intelligent and to build South Korea the first ubiquitous society in the world, thus promoting the economic development and social transformation.

"Sensing China"

As early as 1999, the Chinese Academy of Sciences initiated the research on sensor networks and designed a number of sensor networks suitable for different sensing technologies. On August 2009, the then China Premier, Mr. Wen Jiabao, propositioned a concept of "Sensing China" during his visit to Wuxi Micro-Nano Sensor Network Engineering Technology Research Center. Since then, IoT has been officially listed as one of the five emerging strategic industries in China and was included in the "2010 Government Work Report" (Qian 2015). In China's 12th Five-Year Plan, IoT was clearly regarded as one of the strategic emerging industries and was strongly supported by the government (Li 2012). It was specified in the plan that the Chinese government would focus on promoting demonstration projects and leading roles in nine fields, including smart industry, smart agriculture, smart logistics, smart transportation, smart power grid, smart environmental protection, smart security, smart healthcare, and smart home. China hoped to achieve a number of remarkable breakthroughs in the research, development, and industrialization of IoT by 2015. This goal included the breakthrough of core technologies, the creation of key national standards, the demonstration of the technology via impactful applications, and the initialization of industrial chains. The approach China planned to take was innovation-leading, application-driven, cooperation-based, safe, and controllable (Chen 2013). On March 5, 2015, China's Premier, Li Keqiang, announced an *"Internet +" Action Plan* to promote the integration of mobile Internet, cloud computing, big data, and IoT technologies with modern industries. For instance, "Internet + Agriculture" is one of the efforts. As of June 2019, rural Internet users in China reached nearly 0.225 billion, accounting for 26.4% of China's Internet users. Thanks to the guidance of government policies and the support of broad recognition of the technology, sufficient conditions were created for the development and adoption of "Internet + Agriculture" technologies, which can bring China's agriculture to a new height.

1.3.3 Typical Industrial Applications of IoT

Smart City

Smart City is an advanced form of urban informatization development supported by IoT technologies. The backbone of a smart city is different types of IoT networks which connect different types of sensors spread all over the city for data collection. Supported by big data and cloud computing technology, the insights gained from the collected data were then used to manage all functions, services, and resources in a manner that is effective and efficient. The data collected from citizens, devices, and resources enables the monitoring of the status of critical city operations and almost all aspects of life, covering telecommunication, traffic and transportation, food supply and safety, water and utilities supplies, public health and security, and other essential community services. Aiming at providing improved services to the community, Smart City may also require the use of social networks and other tools to ensure that it will be a people-oriented and comprehensive yet still highly efficient system of urban operation management. A smart city shall have to integrate administrative management, urban planning, emergency respond systems, and other social services. To optimize the efficiency of city operations and services, and to connect them with citizens, smart cities will fully utilize information and communications technologies (ICT) and various physical devices connected to the IoT network. Smart cities also allow city authorities to interact directly with both community and city infrastructure and to monitor what is happening in the city and how the city is evolving.

Smart Healthcare

To gather, store, and process various types of medical data for providing improved care to patients and enhanced technologies to providers, Smart Healthcare depends on IoT as an enabler to seamlessly interconnect patients, healthcare providers, and implantable or wearable medical devices. Equipped with such connectivity among patient, providers, and devices, Smart Healthcare would allow providers to better treat patients using better diagnostic tools, more devices (by taking advantage of external resources), and enhanced expertise (which might be more important for some special cases when local expertise is insufficient). It can enable providers to assist patients in their homes where they can be continuously monitored with the help of numerous Internet-connected healthcare systems and devices. This approach reduces the need for hospitalization, which can be especially beneficial to elderly. In addition, a smart healthcare system can allow patients and health service providers to take advantage of connected medical services by delivering patient's medical data to their health service providers, thus offering a proactive approach to early detection and even prevention of medical conditions. All above can potentially mean significant improvement of life quality for patients and markedly reduced healthcare costs. In summary, Smart Healthcare helps hospitals deliver truly patient-centered medical services through prompt and improved patient care, more effective ways of healthcare delivery, more efficient use of resources, and reduced costs.

Smart Transportation

Smart Transportation, one of vertical applications of IoT technology to transportation systems, is an advanced stage of intelligent transportation that aims to better inform users and to enable them making safer, smarter, and more efficient use of transport networks. The core functions include perception, data mining and analysis, and interconnectivity of vehicles, roads, and control center, all of which realized through integrating sensing, IoT, cloud computing, artificial intelligence, and automatic control technologies with smart management strategies. Smart Transportation provides a real-time interactive information service platform for achieving optimal traffic control and planning at local, regional, and even country level in both temporal and spatial scales for meeting transportation needs of all aspects. Smart Transportation can also include the use of some other innovative technologies, such as vehicle navigation, fleet management, toll and parking services, traffic signal control, and traffic law reinforcement. Such adoption significantly improves overall transportation efficiency and traffic safety to meet the safer, faster, smoother, and more reliable transportation needs of individuals and businesses alike.

Smart Logistics

Smart Logistics, another vertical application of IoT technology in the supply chain, adopts connected devices, such as RFID, GPS, wireless network, mobile Internet, and other intelligent tools, to bring end-to-end visibility in the process of supplying the right product at the right time and the right place and in the right condition to the customer. This IoT-integrated system can utilize data from diverse sources of various formats, in either static (e.g., inventory records) or dynamic (e.g., delivery tracking information), to acquire and analyze needed information for making adequate decisions, decisions that will make supply chains more effective and efficient at each step. For example, a sensor-driven and IoT-connected asset tracking tool can provide users with real-time visibility at each stage of shipment. Such visibility may include conditions of shipment, such as moisture, heat, vibration, and any other interested parameters as the product moves through the supply chain, thereby ensuring sensitive supplies are being handled under right conditions during the entire process. Integrating artificial intelligent technologies, Smart Logistics makes logistics systems imitate human intelligence and bestow upon them the ability of perceiving, learning, and reasoning, allowing them to solve unexpected problems in logistics.

Smart Campus

Smart Campus is an in-depth integration of information technology and teaching. Supported by IoT, cloud computing, and big data analysis, a smart campus system employs various application systems to create a smart learning environment that entails all aspects of campus life, from teaching and scientific research, to student activities and leisure, and to management and decision-making. In general, Smart Campus have three core functions, i.e., providing (1) personalized services to teachers and students using a comprehensive intelligent environment and information service platform; (2) seamless information services to teachers and students by integrating various applications and services using a networked computer system; and (3) an interface for mutual communication and mutual perception between the school and the outside world. Some smart campus products have already been developed, such as smart school gates, future classrooms, electronic fences, smart buildings, etc.

Smart Home

Smart Home is the embodiment of Internet-enabled household interconnection. Developed for residence house, Smart Home adopts integrated cabling technology, network communication technology, security technology, automatic control technology, and audio and video technology to connect various devices in the house for building efficient residential facilities and family schedule management system. Smart Home can provide a variety of functions, such as remote control of home appliance, lighting, telephone, indoor and outdoor security monitoring, environmental monitoring, and other programmable devices. In addition, Smart Home can offer a full range of information interaction, thus improving home safety, convenience, comfort, and aesthetics and bringing environmentally friendly and energy-saving lifestyles.

Smart Grid

As an IoT-supported power grid intelligent management system, Smart Grid integrates sensing, communication, computing, and control technologies with a power grid for improved grid management. Aiming to best satisfy user's demand for electricity, a smart grid system manages a grid by taking safety, reliability, economic, and environmental regulations into consideration when optimizing the grid operation. A typical smart grid system consists of four subsystems, including sensing, transmission operation, distribution control, and asset management.

Smart Manufacture

Smart Manufacture is a penetrating and in-depth application of IoT technology in manufacturing industry. It can incorporate, on an on-going basis, into all aspects of industrial production various types of terminals with the ability of situational perception, computing models based on ubiquitous technology, and wired or wireless communications. Therefore, Smart Manufacture could potentially improve manufacturing efficiency and product quality and cut down production costs and resource consumption. The application of IoT in manufacturing is also reflected in supply chain management, production process automation, product and equipment monitoring, safety and environment monitoring, and energy management.

Smart Agriculture

Smart Agriculture is a farming management concept that relies on modern information and communications technology (ICT) to improve both the yield and quality of agricultural products through data-enabled production management. Agricultural IoT systems provide the infrastructure required to interconnect sensors, big data processing and knowledge-based decision-supporting tools, artificial intelligence, and automated implementing equipment for smart agricultural production. For example, an IoT system can integrate various sensing systems for the precise measurement of temporal and special variations of soil and crops within a field. The system can also incorporate a remotely connected intelligent data processing unit for the analysis of the obtained data, thus extracting information that supports decision-making. Furthermore, the system can also incorporate a control center for monitoring and decision-making and an electronic controller for automatic field operations. Similarly, applying IoT-integrated smart agriculture technology to animal farming can help farmers achieve precise feeding based on the monitored needs of individual animals and purposely prevent disease and enhance herd health according to the potential health hazards detected. Various sensors and data communication networks will play critical roles in these smart agriculture practices. Defined more broadly, Smart Agriculture should or could expand its scope to include agricultural e-commerce, product traceability, agricultural leisure tourism, and other relevant aspects, as those components can also impact the productivity, product quality, and profitability of agriculture production. Targeting at upgrading agriculture with respect to the entire production-supply chain, and enhancing agriculture sustainability and competitiveness, Smart Agriculture is an inevitable trend of global agricultural modernization (Lehmann et al. 2012; Talavera et al. 2017; Khanna and Kaur 2019; Villa-Henriksen et al. 2020).

1.4 Agricultural IoT System

1.4.1 Architecture of Agricultural IoT

Agricultural IoT (Ag IoT) is a vertical application of IoT technology in agricultural production, management, and services. It mainly works to connect various sensors and data transmitting networks to promptly perceive major operational information from production sites. Through adequate process and analysis of the obtained data, Ag IoT enables more effective production management by optimizing operation the operation, thus increasing yield and income. The effective integration of IoT and

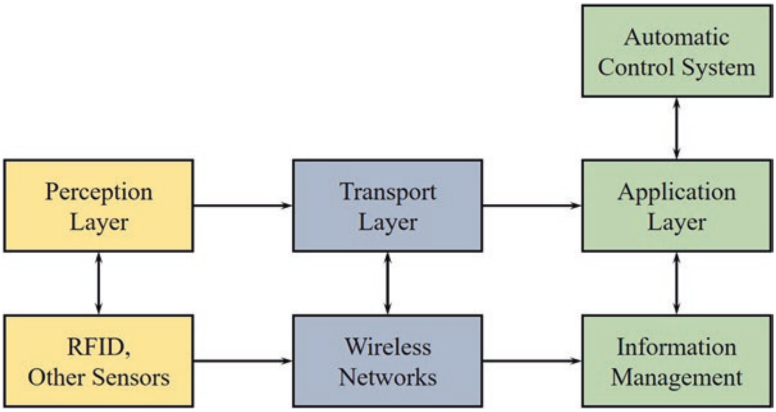

Fig. 1.1 The relationship between three layers of an Ag IoT architecture

agriculture would transform agricultural production from the traditional low-efficiency mode to a data-based intelligent production mode that is focused on higher productivity and profitability.

The typical architecture of an Ag IoT is primarily composed of three layers: the information perception layer, the transmission layer, and the system application layer (Fig. 1.1). Among them, the core components of the information perception layer are sensors. Similar to human's reliance on their vision in observing crop growth conditions, sensors are relied on to acquire dynamic and real-time information. The perception layer in an Ag IoT collects multi-dimensional information of crops, soil, and environment via various sensing technologies. Such information includes, for example, the nutrients, moisture, and vegetation index of crop; the moisture, organic matter, and nutrients of soil; temperature; humidity; light intensity; and so on (Fig. 1.2). The information transmission layer transmits data collected at the perception layer. In Ag IoT, Zigbee, LoRa, GPRS, Wi-Fi, and Bluetooth are commonly used wireless networking means for the transmission of data. The technologies involved mainly include intelligent self-organizing network protocol, low-power and high-reliability transmission mechanism, and so on (Fig. 1.2). System application layer, including intelligent information management system and automatic control system, is used to host data processing, information analysis, intelligent reasoning, and implementation control elements, a function that supports the automated processing of agricultural data, decision-making, and control of agricultural production. Figure 1.3 is a graphic illustration of the basic framework in which this three-layer architecture supports information perception, data transmission, and data analysis for decision-making and for implementing automated control at last (Nie 2012).

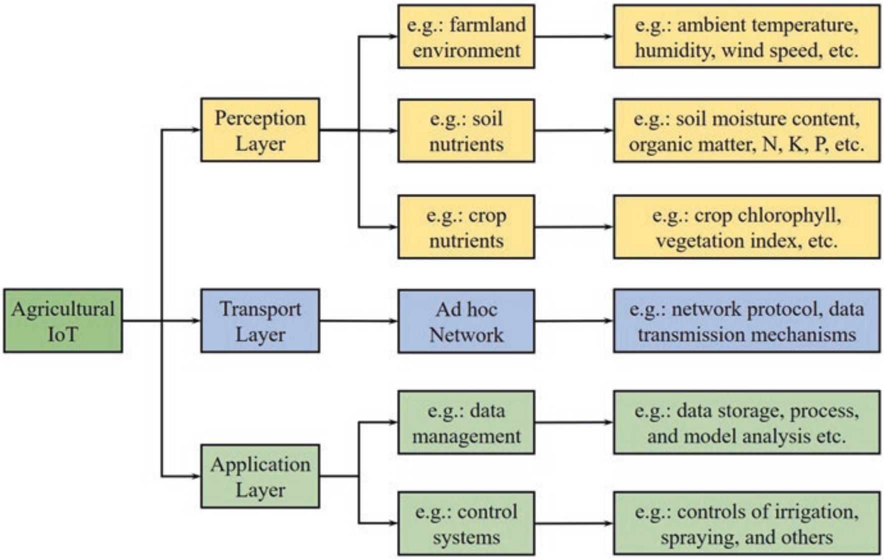

Fig. 1.2 The composition of Ag IoT planting intelligent system

1.4.2 Features of Agricultural IoT

As a wirelessly self-organizing network, IoT has been extensively adopted by many industrial automation systems. Since the end of the twentieth century, developed countries such as the United States, the European Union, Japan, and China have launched research programs on WSN one after another. Well-known programs include SensorIT, WINS, SmartDust, SeaWeb, Hourglass, SensorWebs, IrisNet, and NEST. In the United States, the US Department of Defense, NASA, and other federal agencies have invested heavily to support the research and development of IoT technology.

While Ag IoT is a vertical application of IoT technology in agriculture, there are a few essential differences, mainly on application conditions, between the IoTs for industrial applications and for agriculture. One such difference is the special requirements on network communication protocols for agricultural applications. The network protocols for Ag IoT demand the connection of mobile farm machinery, high-moisture working environments that include in-field irrigation sites, greenhouses, chemical spraying operations, and even animals. In addition, the microclimate of various agricultural productions has certain impact on wireless communication, and the continuous changes of growth states are also likely to exert major impacts on wireless transmission. On the other hand, some of the acquisition of agricultural information do not have to be completed in real time, and a certain degree of delay in the transmission process of such data would not cause much trouble. What all these complicated issues mean is that Ag IoT (He et al. 2013). The

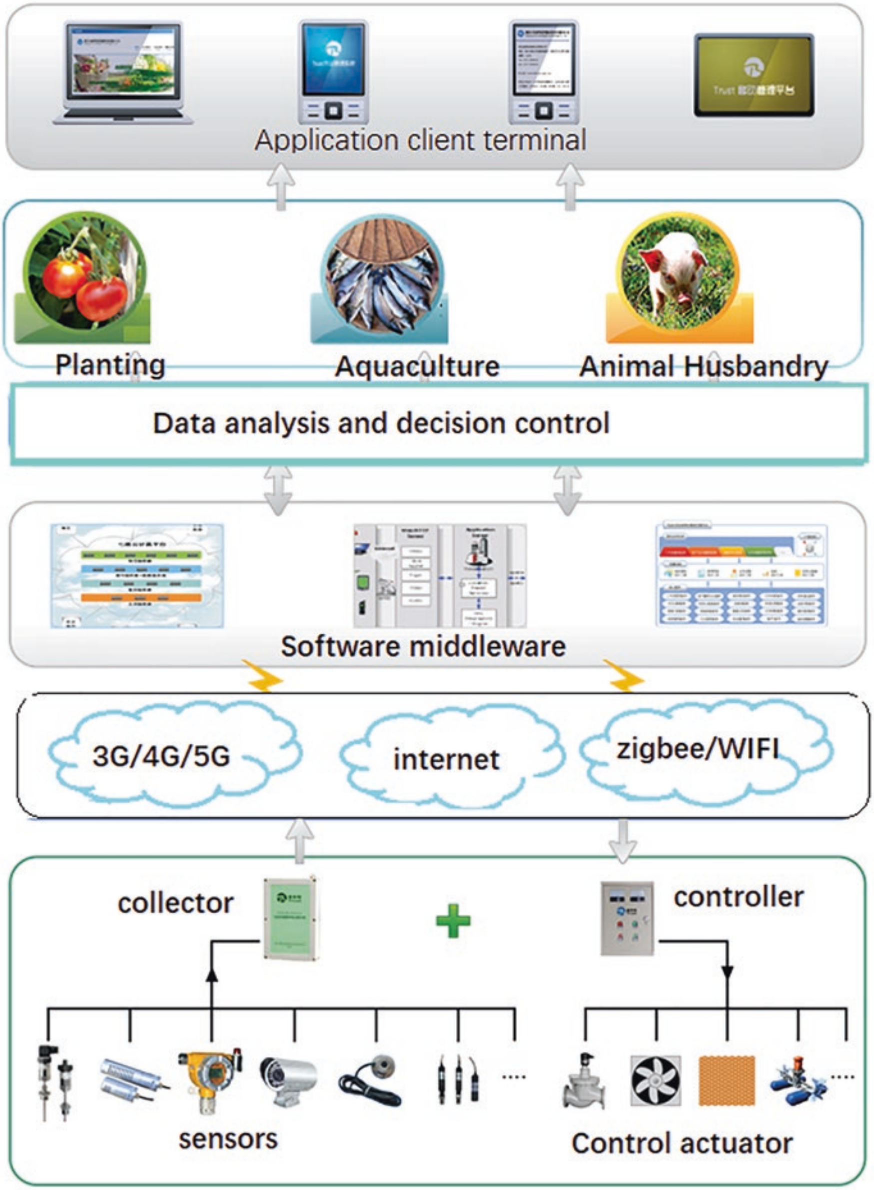

Fig. 1.3 The basic framework of Ag IoT

following sections will briefly introduce some features of sensor nodes and other field devices in an Ag IoT.

1.4.2.1 Sparsely Arranged with Relatively Fixed Locations

In comparison to industrial production, agricultural production generally operates in a low-input and low-output mode, which makes it difficult to densely deploy sensor nodes to acquire production-related data. In addition, deploying too many sensor nodes in a field can also interfere with normal field operations, especially in mechanized operations. Therefore, the sensor nodes in Ag IoT are sparsely arranged, and a relatively long distance between the nodes is often required. To collect the typical data from a large area of agriculture sites, one common practice is to divide a field into multiple sampling zones and place one sensor note in each sampling area. Such practices are founded on an assumption that the soil, crop, and environment parameters in this sampling area maintain approximately constant values, so that the typical data can be determined. As many of the agricultural lands are confined by natural boundaries, such as roads, rivers, and terrain edges, with some irregular shapes, the zoning of sensor nodes is also often irregularly determined. Once the sensor nodes are installed, their locations are rarely adjusted for collecting comparable temporal data from the field.

1.4.2.2 Long-Distance Data Transmission and Low Power Consumption

In typical Ag IoTs, a long distance of wireless data transmission is generally required between in-field sensor nodes, and their distance to the data receiving center and the control platform could also be far away. What this means is that long-distance wireless transmission of the data collected by sensors is essential in many agricultural applications, especially for those deployed to farmland. In addition, the sensor nodes placed in farmland often rely on batteries or solar chargers for power supply. Therefore, it is highly desirable to have sensor nodes featured low power consumption suitable for long-term use.

1.4.2.3 Working Under Extreme Environment

Agricultural production is generally conducted in natural environment where extreme conditions frequently appear, such as abnormally hot or cold temperatures, heavy rain/snow falls, or super strong winds. IoT devices installed in field are expected to work properly and reliably under all those conditions. Therefore, one fundamental requirement for Ag IoT devices deployed in field is the ability to cope with such extreme environment conditions, especially the resistance to extreme temperatures and waterproofing. In addition, field workers often lack the ability to perform routine maintenance of IoT devices. This makes it more challenging to keep Ag IoT devices stable, reliable, and durable with minimum maintenance needed. If possible, certain self-diagnosis and automatic tuning or adjustment functions are highly preferred.

1.4.3 Application of Agricultural IoT

In the past couple decades, many countries, such as the United States, the European Union, Japan, and China, have undertaken a number of research programs on applying IoT technologies to agriculture. The applications of IoT in agriculture include field automation of crop and animal production and automation of agriculture and food supply chain. Such applications offered farmers with data-enabled and practical means for interactively managing their production in a more effective and efficient way. At the same time, it also promotes the interconnection of Ag IoT and other IoT applications, contributing to the establishment of ubiquitous IoT. While some products of sensing devices, connectable to IoT, became commercially available, most of them are still in the development and experimental stage. A large space of improvement still exists with regard to important performance parameters of products, such as stability, reliability, and power consumption.

1.4.3.1 Application in Field Crop Production

In production, the applications of IoT mainly include the continuous monitoring of field conditions, which enables a few automated functions. For example, the sensing unit monitors plants and/or soil water or nutrient stresses to provide the needed information for automatic irrigation or precision fertilization. Hamrita and Hoffacker (2005) developed a prototype system which integrated a few sensors using RFID tags to monitor comprehensive soil information in real time. Zhang et al. (2009) designed a multi-sensor information monitoring system for growth information that includes crop spectra, multispectral image, canopy temperature, ambient temperature and humidity, and light on canopy. The system monitors crop nitrogen and water stresses. To improve the management of wheat production, Xia et al. (2013) developed an IoT-based remote diagnosis and management system for wheat seedling, which measures the physiological and ecological characteristics of wheat. Additionally, the system is fused with historic weather disaster indicators to create adequate wheat management plan for different growth stages under disastrous weather conditions. A few other examples include the development of a farmland environment monitoring system based on WSN reported by Bhanu et al. (2014), an innovative multi-agent system based on virtual organization reported by González-Briones et al. (2018), and a remote monitoring system for drip irrigation based on solar power designed by Liu (2019).

1.4.3.2 Application in Aquaculture and Livestock Farming

In aquaculture, Ag IoT is primarily used to monitor water quality and aquatic product conditions for regulating the carbon dioxide concentration, temperature, and feed, so that optimal growth conditions can be created. Meng et al. (2015) developed an online monitoring system that consisted of an automatic cruise drone, an environmental monitoring device, and a remote service platform. This system was installed on an unmanned ship which can be automatically and safely guided to desired sampling points to perform location-specific measurements on water temperature, dissolved oxygen, pH value, redox capacity, as well as ecological information of fish and shrimp. Parra et al. (2018) developed a system to monitor water quality, feed conditions, depth, and speed of swimming in aquaculture ponds. In addition, this system contained an intelligent energy management algorithm for the automatic control of data transmission using an energy-saving mode. Sun and Chen (2019) designed an IoT water quality monitoring system to remotely monitor and manage water quality in terms of water temperature, dissolved oxygen, pH, and a few other parameters.

An enabling environment for livestock and poultry production can effectively prevent and reduce the incidence of diseases and promote the rapid growth of livestock. IoT here is mainly used to monitor the production environment and animal conditions, thereby realizing automated control, which creates optimal growth environment. For example, Godas et al. (2015) designed a sensor-based system called Sheep Manager for monitoring and managing sheep milk production. The system adopted near-field communication (NFC) technology to identify sheep and used sensors to measure and record milk yield of individual ewe in real time. Saravanan and Saraniya (2018) developed a livestock management system based on cloud IoT which employed UID identified wearable collars as sensors to monitor and record physiological parameters of animals, such as body temperature, standing, eating, heartbeat, as well as ambient air temperature and relative humidity, to perceive and predict animal's health status. To develop adequate methods for livestock facility monitoring, Li (2018) conducted a parametric study that combined multiple technologies including signal processing, intelligent computing, and machine learning to determine the impact of some commonly measured parameters on the overall environment.

1.4.3.3 Agricultural Logistics

Qian et al. (2012) developed a wheat flour traceability system (WFMTS) which combined barcode and RFID technology. This system has been put to use in a wheat flour mill in China. Li et al. (2017) proposed an IoT management platform capable of tracking the supply chain of prepackaged food in real time. Integrating QR codes and RFID tags, this platform enabled fine-grained tracking of the supply chain at low costs. In order to track food logistics in real time, Tian (2017) attempted to build a traceability system for food supply chain based on hazard analysis and critical control points (HACCP) and blockchain and IoT technologies. Wang et al. (2018) designed a wireless multi-sensor system to monitor and analyze key parameters of fresh-cut branches of North American holly, including temperature, relative humidity, and concentration of carbon dioxide and ethylene in the cold chain environment. According to the results of the analysis, the cold chain environment can be improved, and early warning can be provided to improve the post-harvest quality of fresh-cut branches of North American holly.

1.5 Development Prospects of Agricultural IoT

It is reasonable to expect that Ag IoT would evolve into a ubiquitous system that gives identities to everything, ranging from a cow to an apple tree, thus keeping consumers informed about where their foods were grown or raised as well as how were they grown, processed, and handled throughout the entire supply chain. Such functions ensure the purchase of safe and nutritious food. Interconnection of all agricultural and food products can be truly realized. In a nutshell, Ag IoT will penetrate into the whole process of agriculture and food production chain and play a huge role in human life.

1.5.1 New Opportunities for Agricultural Sensor Research

As the "eye" for perceiving information related to agricultural production, field sensing technology plays a vital role in the information perception layer of Ag IoT. Some of the common requirements for developing new field sensors include low costs, low maintenance, self-adaption, high reliability, and low power consumption.

1.5.2 Integration of Agricultural IoT and Automated Field Machinery

As a general trend, agricultural machinery now features more automatic and/or intelligent functions, some of which are now wholly autonomous. As the executive link in IoT-supported agricultural operations, agricultural machinery should evolve into an automatically or remotely controlled in-field execution system of the IoT. For example, IoT-supported variable fertilizing operation would require automatic or remotely controlled real-time application. Such operations demand effective and reliable data communication between the IoT system and the mobile field machinery. A machine area data network (Zhang 2007) can serve as a node for integrating a mobile field machinery with an Ag IoT system to achieve effective and reliable data communication.

1.5.3 Integration of Agricultural IoT and Food Supply Chain

As a technology capable of monitoring the entire process from production, processing, transportation, to circulation/consumption of agricultural products, Ag IoT will play increasingly important roles in the food supply chain, roles like providing the needed traceability for food safety (Christopher et al. 2017). Traceability allows consumers to be aware of how their foods were produced, for instance, what fertilizers and pesticides were used under what condition; how was it processed, stored, and/or transported under what safety/quality control measures; and how was it handled in the circulation/consumption stage. Thus, the integration of Ag IoT system and food safety traceability system will provide an effective and practical means to ensure food safety and protect consumer rights.

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