Mini-review of application of IoT technology in monitoring agricultural products quality and safety

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Abstract: Internet of Things (IoT) technology has been identified as one of the emerging technologies in information technology (IT), which is widely used in all walks of life in the world. The key technologies of IoT technology, such as radio frequency identification (RFID), wireless sensor network (WSN), sensors and global positioning system (GPS), had been widely used in farmland and greenhouse management, environmental monitoring, cold chain monitoring and tracking, and traceability, etc. As advancements in science and technology, IoT technology has been widely applied in agricultural products quality and safety, which brought a number of potential benefits for detecting agricultural products easier and automatically, improving the efficiency and speed of operations, decreasing the labor cost, promoting the agricultural products quality and safety. This paper intended to introduce the concept of IoT technology, the key technologies used at present and review the recent applications of IoT technology in monitoring agricultural products quality and safety in the whole industry chain, such as production, processing, circulation, sales and traceability. Challenges and trends of agricultural products quality and safety in the future were also discussed.

Keywords: IoT, agricultural products, quality and safety, RFID, WSN, sensors, GPS
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1 Introduction

Concerns of agricultural products safety have grown steadily during the past decades. Modern consumers expect that agricultural food not only fresh, nutritious, and palatable, but also safe. Besides they also wish that the foods they buy and consume in various ways are with good quality and adequate shelf life[1]. However, agricultural products safety remains a severe problem in the world wide. In recent years, agricultural products safety scandals happened one after another, as 'dioxin eggs', 'cadmium rice', 'poisonous bean sprouts', 'lean meat powder pork', 'horsemeat'[2-4], etc., which lead to public health threats and drew public attention. Therefore, improving agricultural products quality and safety is an important research topic in the world. In particular, agricultural products quality and safety is the fundamental factor in the food sector.

Agricultural products quality and safety is not only related to the public health, but also affected social stability, economic development and national security, which become a global issue with a growing concern. Agricultural products can be affected by pesticides, heavy metals, microorganisms and other harmful substances pollution during production, processing and transportation[5,6]. Agricultural products quality and safety run through the whole food chain from farm to fork, and determined by a number of links and economic organizations. Ma et al.[7] established a quality and safety supervision technology evaluation index system for agricultural products sold in the e-commerce environment, which evaluate the quality and safety supervision of agricultural production in six areas, including the environment, production, primary processing, transport, storage, and distribution. But the real-time monitoring in the production, processing, circulation and sales of agricultural products have always been difficult. Modern technologies should be used to solve the problems.

Internet of things (IoT) technology will bring a new revolution of world information industry after the computer, internet and mobile communication network, which break the traditional ideas and open a new technical field. And it is composed of three dimensions concluding information items, independent networks and intelligent applications. IoT technology is the integration of heterogeneous smart devices and interoperable communication technologies, such as RFID, WSN, sensors, GPS and actuator networks etc., which are capable of identification, tracking, communication, monitoring and interacting with things[8-10]. IoT technology is entering a new phase. As the development of smart and network technology enabled objects with communication, sensory and action capabilities, the application of IoT technology refer to the areas of environment monitoring, transportation and logistics[11], smart traffic[12], smart buildings[13,14], healthcare[15], public safety[16], etc.

As providing flexible control mechanism for acquiring on-field parameters in real time, IoT technology has become a potential solution to various agricultural applications[17,18]. IoT-based agricultural products applications cover irrigation, precision

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agriculture, greenhouse, cold chain control, M2M-based machine and process control, environmental monitoring, traceability, and quality monitoring[19]. IoT technology develops based on the development of the Internet. Advance in IoT technology continue to change the ways of agricultural products monitoring. Agricultural products quality and safety was obviously improved by using IoT related technology. The objective of this paper was to review the recent applications of IoT in monitoring agricultural products quality and safety in production, processing, circulation, sales and traceability. It had also discussed the current challenges and trends in the future.

2 IoT focused technologies

IoT has been identified as one of the emerging technology in IT, and has many definitions in the research field, due to a different underlying vision with a different background. IoT also poses an extraordinary system, which is replete with conceptual and technical challenges. Authors concluded the definitions of IoT technology from different visions. As identified by Atzori et al.[8], they distinguished IoT technology in three paradigms: (a) things oriented layer (sensors), which focuses on the 'objects' and finding a paradigm able to identify and integrate them, (b) internet oriented layer (middleware), which emphasizes on the networking paradigm and exploiting the IP protocol to establish an efficient connection between devices, (c) semantic oriented layer (knowledge), which aims to use semantic technologies, describe objects, manage data, store, interconnect and manage the huge amount of information provided by the increasing number of IoT objects. Zheng et al.[20] defined IoT as comprehensive perception, reliable transmission, and intelligent processing, and classified it into three layer architecture: sensing layer, network layer and application layer. In this section, we discuss the practical and mature technologies and equipment's applied on IoT, such as RFID, WSN, Sensors and GPS technologies, which are the most commonly used technologies in IoT system[21].

2.1 RFID technology for IoT

RFID technology was defined as an automatic identification and data capture (AIDC) technology, which considered by scholars as the core of IoT[22]. Usually, a RFID system consists of three parts as shown in Figure 1: (a) a tag containing a chip, which embedded or attached to a physical object to be identified; (b) a reader and its antenna, which allowed tags to be interrogated and responded without contact; (c) a host computer, which equipped with a middleware application that managed the RFID equipment, filtered data, and interacted with enterprise applications to support intra- and inter-organizational business transactions. And there are four frequency bands currently depending on the application: low frequency system at 125 kHz, high frequency system at 13.56 MHz, ultra-high frequency system at 433 MHz or 868 MHz in Europe, and microwave RFID tags using the 2.4 GHz or 5.8 GHz band[23].

RFID tag has an embedded microchip which allows it to store data, and an embedded antenna to transmit this information. There are three types of RFID tags as active, passive and semi-passive. Active tags have a tiny embedded battery to supply power, allowing their own signals constantly emitting, and the tags have a greater range of communication range, higher rate of data transmission, and larger capacity of data storage than passive tag. The active tags provide longer reading distance, and can communicate over 100 m or longer distance. Appropriate tags should be chosen according to the different application areas.

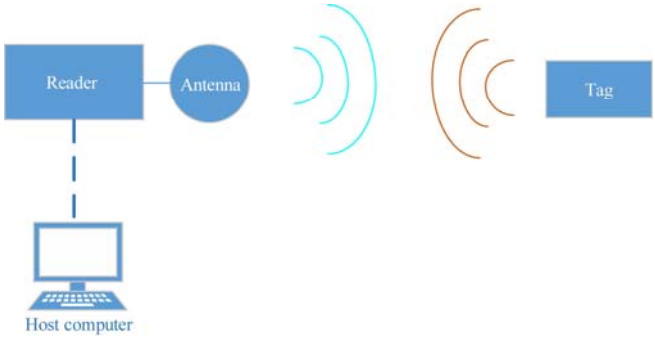

Figure 1 Architecture of a RFID system

Compared with previous technologies, such as bar code and two-dimensional code, RFID tag has several advantages, including unique item/product level identification, no need of line of sight, multiple tags items reading, more data storage and data read/write capabilities[24,25]. It can also correctly show the real-time locations information of objects. Meanwhile, RFID technology has the ability to penetrate certain goods and read a tag that placed in containers, embedded in any object or injected into animals which is not visible[26]. RFID tag can be equipped with different types of sensors in order to collect various parameters as humidity, temperature, pH, light and gases[27,28]. Combined with hardware and software, RFID tag can carry out additional functions such as real time monitoring, environmental sensing, and tracing. However, RFID also have several disadvantages. Tag and reader costs are more expensive than bar code, and the limited life of the power batteries which should be changed manually. Active tags usually have much more far communication distance, but their prices are relatively higher, which mainly applied in the field of valuables remote detection. Passive tags are cheaper than active tags, but their working distance and storage capacity are restricted by energy sources.

RFID technology was classified in the sensing layer of IoT technology, which can potentially assist in improving the efficiency of manufacturing. RFID technology was widely applied in supply chain, logistics, healthcare, environment monitoring, agricultural products monitoring and military areas[29-32]. In current, RFID had been also widely applied in agriculture, such as precision farming, irrigation, agricultural environment monitoring, cold chain experiences, agrifood traceability and safety, etc.[33]. RFID technology is increasing at a fast rate which seems to be able to bring great opportunities, and application of this technology will be promote the development of modern agriculture in China. With the technology developing, the use of RFID technology in agriculture will be expected to increase rapidly in the future, which brings more applicability opportunities. Exploring the impact of the vast amount of data generated by RFID should be studied in future research[34].

2.2 WSN technology for IoT

WSN has been widely considered as one of the most significant technologies in the twenty-first century, which was a collection of nodes organized into a cooperative network. The hardware architecture of WSN consisted of four components: sensing unit, processing unit, transceiver unit and power unit[35], and the architecture of WSN system was shown in Figure 2. Thus, it carried out three functions of data acquiring, processing and transmitting, and used battery-operated computing and sensing devices. A typical WSN normally consists of a large number of

distributed tiny sensor nodes organizing themselves into a multi-hop wireless network operating on limited battery power, and coordinate to perform a common task or monitor an area of interest. Each sensor monitored various conditions like temperature, humidity, pressure etc., collected the data, converted it into electrical signal and communicated directly to the base station or among each other. Each node had one or more small sensors with embedded processors and low-power radio transceivers in order to sense external events.

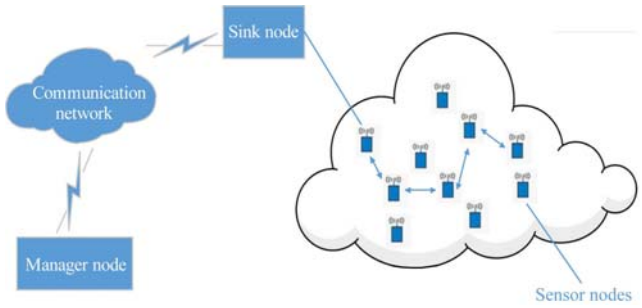

Figure 2 Architecture of a WSN system

WSN is a combination of Micro Electro Mechanical Systems (MEMS) technology, embedded computing technology and wireless communication technology, which can monitor objects in the network region in real time, and process the information to obtain detailed and accurate information. WSN has many advantages, such as wireless, cheap, fast and efficient data transmitting without the cost and mess of the wires. Comparing with traditional sensors, sensor nodes are with small volume and low lost. Most of the data transmitted in the sensor network are processed by the nodes, so the traffic and communication radius is small and the bandwidth is very low[36]. Besides these advantages, there are also many issues such as lack of a predetermined infrastructure of networks, limited battery power of sensor nodes, disastrous environmental conditions to which sensors are vulnerable, etc.[37]. Because of the limited battery power, energy efficiency becomes one of the most important factors which influencing the networks' performance. Therefore, energy efficiency is the key factor in the design of WSN. Like ordinary networks, sensor networks are also facing the test of security, that is, how to use less energy and computation to complete data encryption, identity authentication and so on. It is also an important research topic to perform the task reliably in the case of destruction or interference.

WSN has become the backbone of the emerging technology of IoT paradigm, which can get organized and they can be adjusted to support different applications. WSN bring richer capabilities for both sensing and actuation to IoT applications. WSN describes the dynamic characteristics of the object in IoT, and plays an important role in narrowing the gap between physical and virtual world. In present, many applications of WSN are being developed, including irrigation, precision agriculture, greenhouse, cold chain control, M2M-based machine and process control, environmental monitoring, traceability, home automation system, military areas, medical systems, fire detection systems, quality monitoring and other commercial areas[19,38-42]. WSN will be an integral part of our future lives after personal computers. With the development of WSN, it will form the network interface between physical and virtual world, penetrate into all aspects of people's life, and so as to change the way of interaction between human and nature. WSN technology has broad application prospects in the future.

2.3 Sensors technology for IoT

Sensors are one of the most critical technologies in the sensing layer of IoT. In the IoT, the only way to get information about dynamic changes is based on sensor technology, which can collect process and transport information. Therefore, it is necessary to study the sensors technology for IoT. The sensors technology has been born in 1860s for more than 150 years, which consists of sensitive elements, conversion elements, conversion circuits, and auxiliary power. According to the basic effects, the sensor works are divided into physical sensor, chemical sensor and biosensors[43].

Chemical sensors are the most active and successful fields. It not only has the advantages of small size, high sensitivity, wide measurement range and low price, but also can realize automatic measurement. Domestic and foreign scholars have devoted to studying on chemical sensors for a long time, and many kinds of chemical sensors of analysis instrument are developed, which helping to improve the people's quality of life. But change and turbulence of external factors will inevitably result in the instability of the sensor's, which will lead to a great impact on its practical application.

Sensor technology is widely used in the environmental protection and monitoring, disease prevention and treatment, and agricultural products monitoring[44-48]. In recent years, it has been also widely used in agricultural products processing and detecting, greenhouse environment monitoring, fruit and vegetable preservation, precision agriculture and grain storage[49-51]. Now, with the rapid development of the IoT technology, sensor technology requirements are increasing. As an important entrance to the data acquisition of the sensor layer of IoT, sensors will also have an explosive growth and move towards high sensitivity and precision in the future. With the continuous development of modern science and technology, traditional single sensor was obviously unable to meet its needs, so fast and low-cost multi-sensor information fusion technology will be the future development trends. Sensors are tending to miniaturization, integration, low consumption, networking and intellectualization. It will become an important technology of intelligent monitoring with its powerful and diverse functions, and its application areas will continue to expand.

2.4 GPS technology for IoT

GPS is becoming part of our daily lives as the Internet, and it can discover and navigate the sea, land and air moving targets, and locate the fixed target on the ground using of satellites and their transmitted signals. The advent of GPS marks the development of star based navigation technology in a brilliant era. The GPS system is composed of three parts: space satellite constellation, ground control system and user equipment[52]. GPS determines the position accurately by using the principle of distance rendezvous, when the real-time position of the GPS satellite is known. Positioning concept has revolutionized by GPS. GPS is a global navigation satellite system that can provide geolocation and time information to a GPS receiver anywhere on or near the earth. Besides its ease of use and worldwide all-weather operation, GPS is popular with the precise positioning, precise navigation and accurate timing functions.

Compared with other navigation systems, GPS has some obvious features and advantages. GPS is global as the distribution of the GPS satellite coverage reaches 98%, at least four satellites can be observed continuously at any site in the coverage of the earth. The observation and measurement by GPS can be carried

out at any time within 24 h of a day, not affected by any climate factors such as cloudy night, fog, wind, rain and snow. GPS can provide high-accuracy 3D coordinates, 3D speed and time information. The positioning accuracy is centimeter level, the speed error is less than 0.01 m/s, and the timing accuracy is 20 ns. With the GPS system and software updating, the general static positioning only takes a few minutes. In the mobile station and base station within 15 km, mobile station observation is only require one or two minutes; a dynamic positioning or speed measurement only need just a few seconds. The operation of GPS is simple, as long as GPS signal can be received, it can be positioned. As the automation of GPS receiver, the workload and labor intensity of measurements are greatly reduces. Since the accuracy of global satellite positioning depends on the location of the receiver and measurement technologies applied, from 100 m to less than 1 cm, the most important error comes from human settings. In complex and hostile situations, GPS was not guaranteed in terms of accuracy. Positioning in the room is inaccurate, and is also affected by many aspects, including buildings, viaducts, waves, and so on.

GPS is in the sensing layer of IoT technology, and is one of the fastest growing information industries in the world. It has been widely used in traffic, navigation, agriculture, environment monitoring, industry, healthcare and so on[53-58]. It has been applied in precise fertilization and spray in agriculture, which can reduce application of pesticides and chemical fertilizers. The combination of GPS satellite navigation and wireless communication technology will promote the overall development of IoT technology, and will become an important direction for the development of GPS technology in the future.

3 Applications in agricultural products quality and safety

With the improvement of living standards, food consumption concept has shifted from 'heat preservation' to the pursuit of safety, green and organic. To improve agricultural products quality and safety, it should be guaranteed 'from farm to the fork' (Figure 3). Agricultural products quality and safety has become a global issue, influencing people's health and the globalization speed of agriculture. IoT technology plays a great role in resolving these issues. The summary of research works and applications of IoT technology in monitoring agricultural products listed in Table 1. Architecture of agricultural products quality and safety based on IoT technology is shown in Figure 4. Then, the application of IoT technology in monitoring agricultural products quality and safety was reviewed from four stages of the whole industry chain, production, processing, circulation, sales monitoring and traceability.

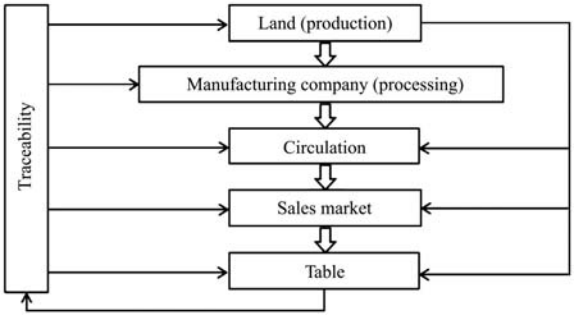

Figure 3 Agricultural products quality and safety from farm to fork

Table 1 Papers on various applications of IoT technology in agricultural products quality and safety monitoring

Application areas	Research objects	Application
Production monitoring	Vineyards	RFID chips were used to monitor vineyards remotely, manage useful data associated with plants and supply a vineyard information map[59].
	Cotton field	Wireless smart sensor array was applied to measure soil moisture and temperature for scheduling irrigation in cotton[60].
	Greenhouse	WSN was used to monitor microclimates in potato, such as humidity and temperature, and reveal the risk of fungal disease[61].
Processing monitoring	Facility agriculture	IoT-RFID, GPS and smart sensors used to monitoring the field and transfer information from the field[62].
	Fruit	RFID and sensor technology were used in dragon fruit pre-cooling link and packaging to monitor environmental data and record package information[63].
	Meat	RFID identification system was developed for determining the exact sequence of animals when entering the slaughtering plant, and information was shared through a collaborative network[64].
Circulation monitoring	Fish	RFID sensors including temperature and relative humidity sensing capabilities were used in an intercontinental transportation of the fresh fish from South Africa to Europe[65].
	Frozen and chilled aquatic products	WSN integrated with Compressed Sending was used to monitor real-time temperature change during frozen and chilled aquatic products transportation[66].
	Pineapples	RFID tags with probe were used to record ambient and pulp temperature simultaneously in pineapples supply chain[67].
	Fruit	ZigBee-Based wireless sensor nodes were used to monitor fruit storage and transport conditions in fruit chambers in real time[68].
	Meat	EPCIS based online system and RFID tags were used to monitoring temperature in cold meat chain[69].
	Chilled tilapia	RFID tag, GPS and mobile communication were combined to manage temperature of chilled tilapia[70].
Sales monitoring and traceability	Cheese	Info-tracing web-based system using RFID code was designed to acquire and link basic information of the cheese, such as origin, producer and quality characteristics[71].
	Meat	RFID, GIS system and mobile phones were combined to acquire the accurate positioning of meat food traceability information[72].
	White wine	RFID technology and WSN were combined to enhance the white wine traceability from vineyard to the consumers' wineglasses[73].
	Wheat flour	A wheat flour system using 2D barcode and RFID technologies was developed to ensure flour quality and safety[74].
	Agricultural products origin	An anti-counterfeit system based on GPS and encrypted Chinese-sensible code was developed to identify the origin of agricultural products[75].
	Fruit	A traceability system based on RFID was designed to trace and record the data of fruit[76].

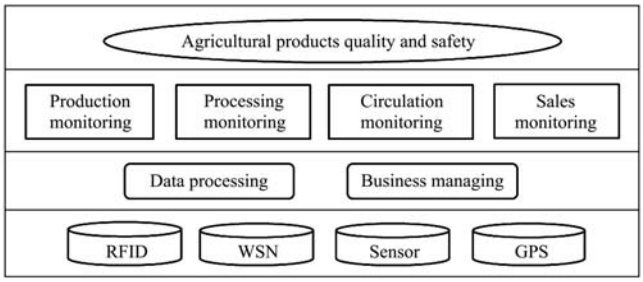

Figure 4 Architecture of agricultural products quality and safety based on IoT

3.1 Production monitoring

Safety agricultural product is produced by agricultural producers, not by regulators or testing. During crop cultivation, information management is becoming an increasingly challenging task for farmers. So an integrated crop management cultivation should be established for data acquiring and the traceability of agricultural products, which can enforce farmers to produce safe agricultural products, with simultaneous respect to the environment[77]. Regarding to traditional solutions, a considerable amount of effort was focusing on IoT solutions for monitoring the condition of the crops during production, for examples, greenhouse monitoring, automated pest counting, remote control of pesticide spraying at user-defined rate and time, etc.

In recent years, several researchers had used IoT technology to collect the required data from the interested regions for their intended usages in various applications. WSN have been used in farm field's management and environmental monitoring. It has become an important technique in environmental monitoring, which can adequately represent the variability in the environment with relatively low cost. Environmental and soil information outdoors can be collected by WSN-based environmental and soil sensors, and location information can be collected by GPS modules. Sensors can also provide risk assessment information, for example, to alert farmers at the onset of frost damage and provide better microclimate awareness[78,79]. Soil moisture plays an important role in crop growth, so water management is necessary. Prathyusha et al.[80] proposed a real-time irrigation control system based on WSN for precision agriculture in Indian, which can monitor and control the irrigation system activities efficiently. The WSN data collecting node modules are connected with different types of sensors, used to monitor the present condition of the field, such as temperature, humidity, soil moisture, pH, etc., that indicated users to provide necessary activities. The method of dripping will reduce huge water losses, and became a popular method as reducing the labor cost and increasing the yields. Zhang et al.[81] used WSN to obtain soil moisture data and GPS as the receiver of geographical information in order to implement effective and water-saving irrigation, and the whole system worked stably and reliably, and the distribution map can be used to guide precision irrigation management. Zhang et al.[82] developed an agricultural environment monitor system based on WSN, which could collect data of the large scale hilly country farmland in south China.

For greenhouse, environment monitoring plays an important role in agricultural production, and many researchers reported the applications of IoT technology in greenhouse. Bajer and Krejcar[83] designed a low cost device for remote control of greenhouse environment using Arduino MEGA 2560 platform, FC-28-B sensors, actuators control and website, to monitor and display indoor temperature, humidity, atmospheric pressure and system states. Other greenhouse environment monitoring technologies based on ZigBee, WSN and web can collect the humidity, temperature, photosynthetic rate and carbon dioxide concentration parameters of the greenhouse in real time, and managers can access, control the system remotely through Internet[84-87]. A WSN based automatic monitoring system was designed to prevent dew condensation in a greenhouse, which was composed of sensor nodes for collecting data, base nodes for processing data, relay nodes for driving devices, adjusting the environment inside greenhouse and an environment server for data storage and processing[88].

Early warning of pests in the field has been a big problem for farmers, and the application of IoT technology may be helpful to solve this problem[89]. Datir et al.[90] developed a real time system that detect Downy Mildew pest in grapes using WSN based on weather data, and it could spray pesticides automatically if disease probability was severed, which reduced the cost of production and enhanced the quality and quantity of grapes. Fernandes et al.[61] developed a framework including a ZigBee end device, which can meet the needs of precision viticulture and precision agriculture.

IoT has been widely used in agricultural products producing areas to monitoring crop growing, irrigation, field environment, pest alarming etc., which could increase agriculture economic benefits and improve agricultural products quality and safety. Farmers' operation records can be accumulated in a database, for example, when, where, and what kind of chemicals and fertilizers were used, etc. Farmers can acquire real-time field information even in the home, and make accurate decisions depending on precise data. Monitoring of the production process using IoT technology can ensure agricultural products quality and safety from the source, reducing chemical pesticides, protecting environment and saving energy. However, there are also many problems in the application of IoT technology. Some agronomists and farmers do not look kindly to fully automated sensing technologies, as they think that they are rich in knowledge and experience on managing the crop.

3.2 Processing monitoring

With the increasing demand for the quality of fresh agricultural products, the demand for the timely response of data acquisition in processing is becoming more and more urgent. Agricultural products processing enterprises must avoid the production mode with poor real-time and incomplete information, and establish a new real-time data acquisition and processing mode, so as to ensure fresh agricultural products quality and safety and improve the competitiveness of market.

After processing the RFID information of agricultural products raw materials, processing enterprises classify and process information according to the information, to determine the processing technology and form of products, and process data such as process parameters, processors, processing time and shelf-life into electronic labels. The batch management has been transformed into a single piece of management, which increases the transparency of the processing[91]. After the harvest and purchase of vegetables and fruits, it is necessary to enter the processing link quickly, because of its short preservation period. Generally, the processing enterprises have read the RFID information of the producing area on the fruits and vegetables while purchasing link. According to the information obtained and the characteristics of the agricultural products, it is necessary to determine whether the agricultural products need to be processed and packed.

Tang[63] developed sensor technology in the pre cooling link to

monitor environmental temperature, humidity, oxygen and ethylene concentration, according to the characteristics of dragon fruit; in packaging, using RFID technology to record the package information, including a package of fruit quality, shelf life, production and packaging enterprise ID; in warehouse, the reader will write the automatically generate batch number into the electronic labels, to match the convenience of transportation and sales and the final product traceability. Li et al.[92] used the RFID technology to write the agricultural products information into the electronic tag, which was one-to-one correspondence with the agricultural product. Information existed permanently with materials, products processing equipment and workers, which were tracked in real time. Using ZigBee and other communication protocol technology, the collected information can be sent to management server in real time, and provide a feasible solution for managers. When problems appear, it can take measures in time and greatly improve the processing efficiency. Barge et al.[64] established a RFID system to determine the exact sequence of animals entering the slaughtering plant, and information was shared through a collaborative network.

With the application of IoT technology, agricultural products processing enterprises can manage the processing equipment, quality of the products and state of workers effectively.

3.3 Circulation monitoring

Agricultural products quality and safety which related to people's health is also affected by the agricultural products circulation, as their special characteristics. Consumers expect to buy fresh and safety agricultural products. Perishable agricultural products such as fruits, vegetables, meat, usually transport in reefer containers to guard product quality and safety, and the environment conditions which are the most critical influencing factors should be monitored and tracked. Therefore, the application of IoT technology is mainly focused on cold chain transportation at present. Different products require different environmental conditions during transportation, so environmental parameters monitoring is important to perishable products. In the past, temperature monitoring systems like strip chart recorders or temperature data loggers were used in the chill chain, which were usually expensive and non-automated. To acquire real-time information in circulation of agricultural products, IoT technology has been used for monitoring conditions of products transportation, as well as for agricultural products processing.

In recent years, RFID and WSN technologies have been widely applied in agricultural products cold chain, to monitor agricultural products location, containers and cold-storage facilities, or monitoring environmental information, quality, safety and senescence of specialty crops during transportation[78,93]. Ruiz-Garcia et al.[68] used ZigBee based wireless sensor nodes to monitor fruit storage and transport conditions in real time, which helped to keep a track over the quality, perishability and freshness of fruits. Mainetti et al.[94] established a system for fresh vegetables supply chain based on innovative Radio Frequency technologies and Electronic Product Code (EPC) global industrial standard, and successfully implemented in an Italian food company which produced ready-to-eat vegetables. Yan[95] developed a fresh produce cold chain traceability system based on RFID, which could ensure fresh produce safety from farm to fork.

Due to the easily deterioration of the agricultural products caused by fluctuating temperatures, real-time temperature monitoring system become an important way to reduce losses and ensure products quality and safety in the circulation link. Ting[96] proposed a system based on RFID, sensor network, 3G network and GPS technologies, which could be connected with the customers' system, so that all the processing, storage, and transportation temperature could be sent to the customers. Then, researchers evaluated the dynamic behavior of temperature sensors within WSN and RFID nodes during cold chain monitoring, and found that they were dramatically influenced by the way they were housed[97]. Xiao et al.[66] developed a temperature monitoring system based on WSN integrated with Compressed Sending (CS) to monitor the real-time temperature change in the refrigerated truck during chilled aquatic products logistics.

Recently, researchers developed a collaborative platform based on IoT technologies, such as cloud computing, GPS, General Packet Radio Service (GPRS), WSN and RFID, to position, identify, communicate, and track in circulation link[98]. The use of IoT can acquire data and monitor the status of the agricultural products in real time, which can reduce the possibility of spoilage, contamination during circulation link to ensure agricultural products quality and safety. And it can also improve circulation efficiency and information accuracy[99].

3.4 Sales monitoring and traceability

When agricultural products were found unsafety in sales link, we should trace their source and take measures to prevent them to be sold to consumers. So traceability is a desirable requirement in modern agriculture, which driven predominantly by international food safety scares[100-102]. Traceability includes the whole process 'from farm to fork', which is becoming a method for providing safer food and connecting producers and consumers. An agricultural product traceability system includes identification of product features, locations of produced, processed, packaged, and stocked of product. Traceability has many benefits to the whole agricultural products supply chain to provide safer food to consumers. It can provide accurate, timely, complete, and consistent information to reduce the risks of agricultural products, and achieving a fast and effective response to emergent events in order to improve consumer's confidents to agricultural products quality and safety. Traceability is an effective method to ensure agricultural products quality and safety, which can also reduce the losses caused by recalls in sales market.

Nowadays the available technologies are alphanumerical code, bar code, and RFID, etc. As RFID has a higher reading rate than traditional barcodes, agricultural products traceability system can become more reliable and efficient. A food traceability system based on RFID was developed to estimate costs and develop an appropriate price strategy in Taiwan, which was used in the chain of convenience stores[103]. An efficient tracing system can make it possible to recall product prospectively and find the factors which caused the problems. Papetti et al.[71] designed an info-tracing web-based system to acquire and link basic information of the cheese, such as the milk origin, the cheese producer, quality characteristics, which can be provided to the final consumer or different food chain actors before or after purchasing. And the RFID code was used to identify the single and specific cheese product. Qian et al.[74] developed a wheat flour milling traceability system incorporating 2D barcode and RFID technology, which providing a significant opportunity to ensure flour quality and safety successfully, and applied in a large wheat mill enterprise in China. Meng et al.[72] combined RFID and GIS technology to acquire the accurate positioning of meat food traceability information, and realized the products trace via taking picture by mobile phones and IoT technology.

Traceability is difficult in the agro-food sector, especially for fresh ready-to-eat (RTE) vegetables. Mainetti et al.[104] used RFID, Data Matrix technology, EPC global standard and Near Field Communication (NFC) technology for the "gapless" traceability of fresh RTE vegetables produced by an Italian agro-food company. Alfian et al.[105] developed an e-pedigree food traceability system based on RFID technology and WSN, to track product location and collect temperature and humidity during storage and transportation, which had been applied successfully in kimchi supply chain in Korea.

Counterfeit and inferior agricultural products not only affected the nations' economic but also damaged people's health. So it is important to identify and trace the origin information of agricultural products to avoid the production and sell of fake goods. Sun et al.[75] designed an anti-counterfeit system to identify the origin of agricultural products based on GPS and encrypted Chinese-sensible Code, and 98% anti-counterfeit labels were correctly identified. Mohammed et al.[106] developed an RFID-enabled monitoring system to ensure that meat purchased from supermarket was truly Halal.

IoT technology used in sales market monitoring and traceability can ensure agricultural products quality and safety to achieve scientific production and management.

4 Challenges

IoT technology has vast potential applications in agricultural products quality and safety monitoring, and many research results are in the stage of transforming to industrialization application, but it also faces some challenges. Different challenges were discussed in this section, such as benefits and costs contradiction, mass data management, information security, standards, and sensing technologies innovation.

4.1 Benefits and costs contradiction

In spite of IoT technology has so many advantages in agriculture quality and safety monitoring, a few company will decide to use it for its additional cost. For examples, RFID has more potential and more advantages, but it can only be applied to "high value" products by food processing industry. The main reason is that tag costs is more expensive than bar code, and the use of tag will increase agricultural products final price, particularly for low-price products, such as fruits, vegetables, grains, etc. Research found that the application of traceability in wheat flour production made the total cost increased by 17.2%, but the sales income increased by 2.5%[74]. Therefore, reduction of tag costs will bring widespread application of RFID systems in agricultural products. Most companies avoid investing capitals in expensive RF sensors and their maintenance. In case the cost decreased, more and more companies will use it[107]. In order to minimize the initial investment, Kang et al.[108] established a simulation to optimize RFID sensor tag-based cold chain systems. Governments' participation is needed to promote the application of IoT technology in agricultural food quality and safety.

4.2 Mass data management

Data management is one of the most important things in monitoring agricultural products quality and safety based on IoT. Huge volumes of data are created by the IoT technology in agricultural products monitoring and traceability process, because data is collected from several different sensors. The huge increase in the daily volume of data in a corporate IT system impacts the hardware cost. A significant amount of real-time sensor data transmission will result in heavy data traffic and overload the communication bandwidth in WSN, and thus reduce the data collection and transmission efficiency[109]. So it is essential to model the huge data produced in tracking and monitoring by an expressive data model. Zhang et al.[110] evaluated an algorithms for big data and self-correction strategies which made sampling and the whole scheme adaptive, and performed well with big data generated by sensors. Many researchers are studying on the technical methods and models for managing the huge data effectively.

4.3 Information security

Data generated by IoT contains a large amount of private information, so information security has been an important problem in the IoT technology application. Data transmission is supported by cable, wireless, mobile and other technology, which may be significant security vulnerabilities and risks, so it asks for new and better techniques for the protection of hardware and software. Babar et al.[111] proposed an embedded security framework as a software/hardware co-design methodology to ensure IoT security. Then, Olivier et al.[112] developed a security model based on the software defined networks architectures, which can secure both wired and wireless network infrastructure, and can be extended to Ad-Hoc networks and network objects, such as sensors, tablets, smart phones, etc.

4.4 Standards

For RFID technical systems, the main problems is a lack of standardization that raise interoperability issues, and efforts for defining standards of operation are being made by researchers[24,65,113]. Standards are an important factor to ensure the security of the IoT information generated by different countries and industries. At present, IoT technology lacks of common interconnection standards. Countries in the world have set up their own technical standards for the IoT, which will bring potential problems for compatibility of subnetworks in the future. Only by following a unified standard protocol, different terminals can be interconnected. Therefore, it is very important to solve the standard problem and establish a unified standard and platform. The problem is not well solved, which is bound to be the bottleneck of the development of IoT. In order to solve this problem, some organizations and alliances have launched standardization activities on IoT technology.

4.5 Sensing technologies innovation

Sensing technologies have been widely used in environmental parameters monitoring, but applications in agricultural products quality and safety detection are relatively few. The development of rapid detection sensors in situ detection using sensing technologies is necessary in the future[114]. The detection sensors should be rapid, portable, and sensitive with good environmental adaptability comparing to the large instruments in laboratory[115]. Continuous power supply capacity and how to improve the accuracy also need to be solved by the sensing technologies used in detection. As two core sensing technologies of IoT, WSN and RFID have their special advantages relatively[116]. Integration of RFID and WSN would provide continuous data monitoring in the whole supply chain, such as maintaining temperature and humidity information that requires throughout product delivery and storage. The integration of WSN and RFID to giving full play to their advantages is the key point of the next stage of research and the future trends.

5 Conclusions and future trends

IoT technology is going to be an established part of life

through communication and network expansion at any time and place[111]. In recent years, IoT technology has been applied in various areas, but less adoption in monitoring quality and safety of agricultural products. Through review on the key technologies of IoT, and the applications in monitoring agricultural products quality and safety from production, processing, circulation, sales of the whole supply chain and traceability, it showed that consumers can acquire agricultural products information for risk management and traceability, and producers can get high quality and yield products with minimum input through precision agriculture based on IoT technology. In present, RFID, WSN, sensors and GPS technology had been widely used in farmland and greenhouse management and environmental monitoring, cold chain monitoring and tracking, and traceability, etc. IoT technology made the monitoring of agricultural products easier, automatic, effective and real-time, which greatly improved agricultural products quality and safety. The establishment and application of agricultural products quality and safety system based on IoT technology, will provide the whole process of tracking and supervising of agricultural products, and meet the public needs of high-quality and safe agricultural products.

Although there are some issues in IoT application, IoT has many advantages and its potential benefits are large. With the application of IoT technology, data information of agricultural products quality and safety can be obtained in real time when the agricultural products enter the circulation market, so that unsafety agricultural products can be effectively prevent into the consumer market, in order to ensure the health of consumers from farm to fork.

At present, the demand for IoT is increasing rapidly, and its application in agricultural products quality and safety is a new attempt for every country in the world. Its future development trend mainly includes the following aspects:

1) New sensors with high sensitivity, high adaptability and high reliability will be developed, which are also embedded, miniaturization, modularization, integration, capture and networking. To enhance their ability to adapt to the environment, and stability, accuracy and reliability of the sensors, manufacturing processes should be improved.

2) Due to the long detection period in laboratory with large instruments and the on-site detection cannot be viable, so it is difficult to monitor agricultural products quality and safety in all aspects timely and rapidly by common technology. Therefore, the development of sensors for rapid detection of agricultural products is a direction of future development, which leads to achieve rapid, accurate and sensitive detection, and prevent the risk of agricultural products entering the circulation field.

3) At present, an important reason for the popularization and large-scale application of IoT is the high cost. How to reduce the cost, and develop new IoT technology is a problem to be solved in the future.

4) Efforts should be taken on the research and revision of relevant standards of IoT, shorten the time for the industry to reach a consensus, unify the interface standards, strengthen global cooperation, actively participate in the construction of international standards, and introduce advanced international standards.

5) How to integrate different dimensions and formats of data obtained from agricultural production, processing and circulation, and get a more comprehensive and objective information about agricultural products quality and safety is the future direction. This requires the development of data fusion technology, in-depth study of deep learning algorithms. Through the deep mining of massive data, the key risk points affecting agricultural products quality and safety can be find, which will be monitored on focus. And the probability of occurrence of security incidents in the future of agricultural products quality and trends will be forecasted.

In the future, more and more IoT technologies will emerge to provide new applications or relevant research opportunities in monitoring agricultural products quality and safety.

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