# Chapter 13
# Agricultural Products Traceability System Applications

**Pengcheng Nie, Yong He, Na Wu, and Hui Zhang**

**Abstract** Against the backdrop that food safety has become an increasing public concern, both national policies and technologies facilitate the building of a food traceability system, whose application has become more and more popular. Thanks to the wide application of agricultural IoT, information about the production, processing, logistics, and market circulation of agricultural products has been collected more thoroughly. Consumers can find out about product information by scanning the traceability code, thereby increasing consumer trust. This chapter lays out an introduction about the application of the agricultural IoT in agricultural products traceability from the aspects of individual identification technology, traceability system structure, and application in planting, livestock farming, and aquaculture.

**Keywords** Individual identification technology · RFID · Bar code · Two-dimensional code · Agricultural products traceability system

## 13.1 Introduction

The International Organization for Standardization (ISO) (8042: 1994) defined "traceability" as "the ability to trace the history, application or location of an entity by means of recorded identifications" (Karlson et al. 2013). According to the Codex Alimentarius Commission (CAC), traceability is defined as the ability to position food at any given stage in its production, processing, and distribution processes. Olsen and Borit (2013) defined traceability as "the ability to access any or all information relating to that which is under consideration, throughout its entire life cycle, by means of recorded identifications." Specifically, traceability includes two aspects. One is to trace back, that is, to trace the process of food and its components along the production chain, hence establishing a circulation history. The second is to trace

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forward, i.e., to trace the food and its components in the production chain. Tracing forward is primarily used to retrieve risky food (Chen 2017). As the trade on food globalizes at ever-faster pace, issues in food safety have occurred frequently. In order to reduce production costs, certain unscrupulous merchants have been engaged in all sorts of fraudulent acts to deceive consumers, including falsification of product origins and adulteration of products. Frequent market fraudulences damage both consumer health and the reputation of local brands and specialty agricultural products. Nowadays, consumers wish, more than anything else, that the quality of food could remain true to their product description and that more information on product origin could be made available. Therefore, traceability of agricultural products is regarded as an essential element to ensure food safety and high quality (Tang et al. 2020).

The purpose of establishing a traceability system is to standardize agricultural production, ensure food safety, enhance technological levels, stimulate brand competition, maintain normal market order, and crack down on counterfeiting and adulteration. This significance of building such a system is that companies can better implement brand and premium strategies, achieve high value-added production and sales, build brand image, enhance corporate value, and connect production, circulation, and management processes. Additionally, they can also provide comprehensive information-based solution of the entire industrial chain and offer reference models and standards for agricultural product standardization and data management. With regard to the government, a traceability system would be conducive to improving the quality control, supervision, and circulation and export trade of agricultural products. Moreover, it would also help standardize the inspection of products. As such, the government is in urgent need of a food traceability system, through which food quality and safety-related information can be acquired for effective supervision, thus improving the effectiveness of supervision and reducing the probability of food safety incidents. When problems do occur, the reasons and accountabilities could be quickly investigated and determined. With respect to consumers, a traceability system would keep consumers informed of relevant product information. In light of the status quo of food safety and the awakening of consumer awareness, consumers should have the right to make informed. A new understanding of food safety is born, and that food safety ought to be reviewed and evaluated from a scientific perspective. The adoption of a food traceability system could eliminate information asymmetries, protect consumers' right to be aware, and enhance public confidence in food (Bosona and Gebresenbet 2013).

The reason why the modern food quality and safety traceability system has been valued and developed rapidly is considered to be the "bovine spongiform encephalopathy (BSE)" crisis since the 1990s, the dioxin contamination that swept Europe, including Denmark and Belgium, and food safety incidents such as the *E. coli* crisis (Pettitt 2001). In 2002, at the meeting of the CAC Intergovernmental Task Force on Food and Biotechnology (Food Traceability System), a number of EU countries proposed a food quality and safety information management system, which is aimed at controlling foodborne hazards, protecting consumer health and ensuring fair trade. Compared with developed countries in the European Union, the establishment of agricultural traceability systems in Asia started relatively late, and most countries are still in the infancy of such constructions. Among the Asian countries, Japan was the earliest one to develop the traceability system of agricultural products. From 2001 to 2005, Japan brought into reality the concept of a traceability system of agricultural product quality and safety. However, India, a major agricultural country, only began to explore the concept and establish related systems in 2006. South Korea also followed this trend and started the development of traceability of agricultural products in 2005 (Feng et al. 2014). The concept of traceability of agricultural product quality and safety in China was proposed by the agricultural department in 2002. In the 2 years following that, China have formulated relevant policies for the traceability of agricultural products and provided corresponding technological support (Zhao 2018). The construction of China's agricultural product quality and safety traceability system began in 2004. It was first implemented in Beijing and Shanghai as a pilot project. After successful implementation, it began to be promoted to other provinces and cities. So far, many provinces and municipalities have set up traceability systems of agricultural products, covering fruits and vegetables, as well as livestock, poultry, and aquatic products.

As time goes by, consumers and merchants are paying more attention to food safety issues and the establishment and maintenance of brands. Under such a background, both national policies and technologies have facilitated the creation of a food traceability system. Greater efforts have been made in this regard, and the application of the system have become increasingly popular. If a traceability system for agricultural products is established, once a safety problem that endangers human health is discovered, the location of the hazard can be determined by reverse research based on information recorded in the entire process from the supply of raw materials to the consumption of the finished product, and the hazard can then be controlled and blocked from the source. At the same time, the product flow can also be tracked forward, and unsold foods can be promptly retrieved to prevent any possible escalation of the problem, thus protecting the health of consumers and minimizing economic losses. Through the establishment of this system, government or risk managers can also achieve science-based and effective supervision. Owing to the adoption of new technologies such as big data, cloud computing, and the IoT in agricultural and food production, more comprehensive information can be collected and analyzed, and timely and reliable information transmission channels between producers and consumers can be established to build stronger consumer trust. Meanwhile, information collection and analysis can in turn generate more positive feedback for improving the quality and efficiency of production and for saving production costs in all aspects. Based on the above reasons, food traceability has become a focal point in research that ensures and improves food quality and safety.

## 13.2 Individual Identification Technology

### *13.2.1 Principles and Applications of RFID Technology*

#### 13.2.1.1 Principles of RFID Technology

RFID radio frequency identification is a wireless communication technology that can automatically identify target objects and read and write data through radio signals. As a noncontact automatic identification technology, the identification process does not require manual intervention; RFID radio frequency identification can withstand multiple types of harsh environments, including severe shock, vibration, electromagnetic environments, extreme temperatures, and chemical corrosion. In addition, RFID technology can be used to identify objects that are moving at a high speed and to read multiple tags in batch. Furthermore, the technology is fast and convenient to deploy.

An RFID system usually consists of a tag, a reader, and an antenna:

- The tag, also known as transponder, consists of a tag chip and a tag coil. Each tag stores a unique electronic code and is attached to the object to determine the item-level target object code.
- The reader is a device that reads or writes tag information. Consisted of a radio frequency module and a signal processing module, the reader usually features a handheld or fixed design.
- The antenna is a device that establishes a wireless communication connection between the tag and the reader to achieve the spatial propagation of radio frequency signals.

The basic working principle of RFID technology is that when the tag enters the reader's magnetic field range, the microchip circuit is activated by the energy obtained by the induced current. The chip converts the electromagnetic waves and then sends out the stored product information (passive tag). Or the tag would use the battery installed in the tag to provide energy to actively send product information stored in the chip (active tag). The interpreter decodes the received product information and sends it to the central information processing system for data processing, hence achieving management control.

Some systems are also connected to an external computer (upper computer's main system) through the RS232 or RS485 interface of the reader for data exchange.

The specific working process of the system is as follows: the reader sends a certain frequency of radio frequency signals through the transmitting antenna to form an electromagnetic field area, which is its working range. When the electronic tag enters the magnetic field area of the transmitting antenna, an induced current will be generated due to space coupling, and the electronic chip microchip circuit will be activated to obtain energy. When activated, the electronic tag modulates such data as its own code onto the carrier and sends it out through the card's built-in transmitting antenna. The receiving antenna of the reader receives the carrier signal sent by the electronic tag and transmits it to the reader. The data processing circuit demodulates and decodes the received signal containing data information and then sends it to the background system for further processing. After the main system confirms that the card is legitimate through logical operations, it makes corresponding judgments and commands according to different pre-settings and then sends instruction signals to control the executing agency to perform corresponding operations.

Fundamental differences exist between different contactless transmission methods in terms of coupling methods, communication processes, frequency ranges, and data transmission methods from RF cards to readers. However, all RFID systems are similar in their basic principles and design structures. All readers can be regarded as consisting of two main modules, namely, a high-frequency interface and a control unit.

The high-frequency interface works to generate high-frequency transmission power that provides energy to activate the electronic tag. It modulates the transmitted signal and sends related data to the electronic tag. Furthermore, the interface receives the high-frequency signal sent by the electronic tag and completes demodulation. Refer to Fig. 13.1 for the schematic diagram of the high-frequency interface of the inductive coupling system.

The control unit enables the communication with the application system software and receives and executes the commands it sends. It is additionally responsible for the encoding and decoding of signals and the related control of the communication process with the electronic tag (master-slave principle). In the event of extraordinary circumstances, such as conflicts and interference caused by overlapping working areas of readers, the unit deploys anti-collision algorithms. Apart from this, it is responsible for the encryption and decryption of related data transmitted between the electronic tag and the reader, as well as the identification of the electronic tag and the reader.

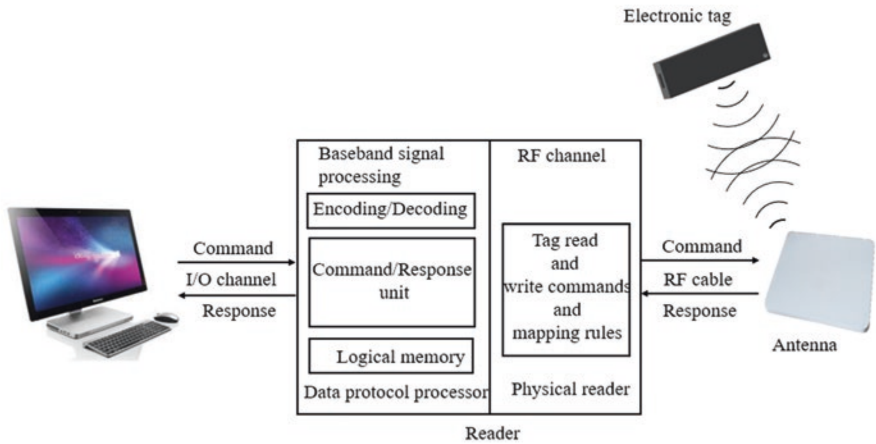


**Fig. 13.1** Principles of the RFID system

Read-write distance is a key parameter in RFID systems. At present, long-range RFID systems are quite costly, which is why it is essential to study the long-range reading and writing methods of RFID systems. The factors that affect the read and write distance of the system include the output power of the reader, power consumption of the electronic tag, the receiving sensitivity of the reader, the antenna operating frequency, the Q value of the antenna and the resonant circuit, the coupling degree of the reader and the electronic tag, the antenna direction, the energy obtained from the conversion of electronic tags, and the energy consumed to send product information. The writing distance of most RFID systems is approximately 40–80% lower than the reading distance.

#### 13.2.1.2 RFID Electronic Tag Applications

**Identification of Livestock**

Recent years saw the continued global outbreak of animal epidemics, causing huge economic losses and seriously endangering people's health and life. To cope with such outbreaks, governments across the globe have begun to attach importance to the prevention, supervision, and control of animal diseases. They have applied radio frequency identification technology to the animal husbandry industry, implemented tracking and identification of animals, and enhanced animal traceability mechanisms. The international standards IS011784 and ISO11785 also stipulate relevant code structures and technical guidelines for animal identification using RFID systems in the production management of livestock. When an animal that wears an electronic tag enters the working area of a fixed reader or when a handheld reader approaches an animal that wears an electronic tag, the reader, whether fixed or handheld, can automatically identify the animal-related information stored in the electronic tag.

There are four common approaches to install the transponder: collar type, ear tag type, injection type, and pill type (Zhao et al. 2012; Wang et al. 2011):

- The collar-type transponder, mainly used in automatic feed distribution system and automatic counting system of milk production, can be recycled among different animals.
- The ear tag transponder (shown in Fig. 13.2) can receive and read related data at a maximum distance of 1 m. Compared with bar code ear tags, it is more suitable for automated breeding processes. As related technologies mature, its cost is going down, giving it the potential to replace barcode ear tags.
- Compared with the above two approaches, the injection transponder is a new comer – its application only begun in the past decade. The principle of the injection transponder is to use special tools to place the transponder under the skin of the animal to be identified. However, this installation method may cause the reader to not read data normally due to the unstable position of the transponder.
- Pill-type transponders, installed in acid-resistant cylindrical ceramic crusts, constitute a highly effective installation method. Once the pill-type transponder is

**Fig. 13.2** Individual animal identification with RFID

placed in the fore-gastric page of the ruminant, the transponder will accompany the animal throughout its life to identify its individual information.

**Application of RFID in the Field of Agricultural Product Logistics**

In recent years, the rapid growth of urban transportation and logistics has made vehicle scheduling and management more difficult. At present, the management of most transportation vehicles also depends on manual recording and transmission. With the increase of vehicles and related business, manual operations will inevitably result in omissions and errors. Meanwhile, the cost of time and the circulation cost of internal information have also continued to increase, and data on transportation cannot be tracked and recorded, leading to increases of operational risks and uncontrollable factors. Moreover, subsequent development and managerial costs have also encountered bottlenecks. Therefore, the operation reform of the urban transportation and logistics is inevitable. As a key technology in the IoT, RFID technology is widely used in intelligent transportation and warehouse logistics management.

As shown in Fig. 13.3, in the process of warehouse cargo turnover and logistics, each piece of cargo and each vehicle is equipped with RFID tags. The basic information of the goods and real-time information of the cargo turnover or logistics process are written into the RFID tags and are associated with the background database. RFID readers ought to be installed at the gates or garage doors that require information registration, so that when the vehicle passes, the RFID reader automatically recognizes, collects, and manages the tag information of the vehicle and goods without manual intervention, improving the efficiency of information transmission and realizing automatic management. The data is transmitted to the background

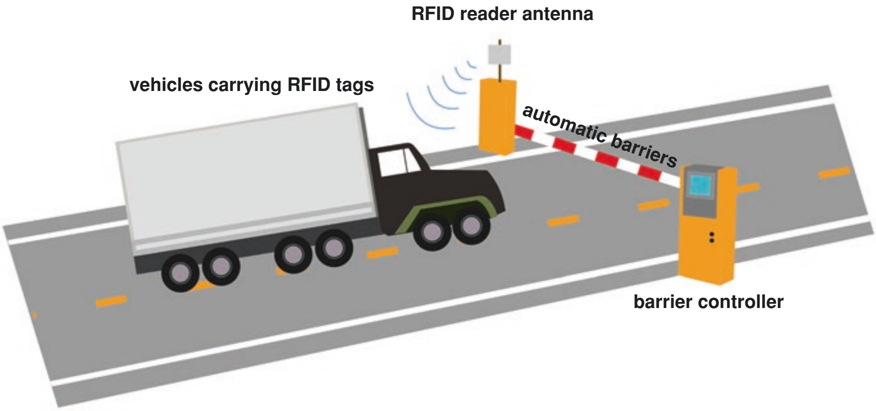


**Fig. 13.3** Application of RFID vehicle management system

management platform through the network to verify the legitimacy of the electronic tag information and then process the relevant data information and issue the corresponding instructions. At the same time, a GPRS module must be installed on each vehicle. During transportation, information is transmitted to the background management platform in real time through the GPRS module installed on each vehicle. By adopting such an approach, the transportation process can be better controlled, and the vehicles can be reasonably dispatched.

Application process and principle of RFID electronic tag:

- Vehicle intelligent access management: When a vehicle, equipped with a radio frequency identification tag, passes the gate, the fixed reader automatically communicates with the electronic tag, eliminating manual operations, so that the entry and exit of vehicles could be faster and more efficient. Relevant information such as the entry and exit records are sent to the background management platform by the electronic tag through the network. The combination of the back-office management platform and the vehicle closing gates can determine the legitimacy of vehicles entering and leaving and provide independent, efficient, and uninterrupted storage and logistics data collection and monitoring functions.
- Information processing: In the field of warehouse and logistics information management, the function of radio frequency identification electronic tags is to store information on cargo transportation and logistics. RFID tags are regarded as electronic ID cards of vehicles because of their non-reproducible and unchangeable characteristics and excellent security performance. It is worth mentioning that each RFID tag has a unique ID number. Throughout the entire process, the newly collected data is compared with the original data in the database, the information is managed, the decision-making process is performed, and the corresponding instructions are given to help staff make decisions and find the appropriate vehicles in a manner that is quick and accurate.

- Real-time tracking management: Relying on GPRS technology, information, including whether the vehicle is parked halfway during transportation, why it is parked, and the vehicle's driving trajectory, can be detected. What this means is that the management platform can track and record the state and location of vehicles. Dispatchers stay informed of the conditions of the delivery vehicles through the management platform, allowing them to react instantly to emergency situations.

### *13.2.2 Bar Code Individual Identification Technology*

Bar codes are composed of "bars" and "spaces" of varying widths arranged according to certain rules. Bar code information is transmitted by bars and spaces with varying reflectivity through different widths and positions, and the amount of information depends on the width of the bar code and the accuracy of printing. The wider the bar code, the more bars and spaces are arranged, the greater the amount of information stored in the bar code. The higher the accuracy of bar code printing, the more bars and spaces that can be accommodated in the same width, and the greater the amount of information stored in the bar code. This bar code technology can only store information through the combination of "bars" and "spaces" in one direction, which is why it is called "one-dimensional bar code." For individual identification, a one-dimensional bar code is scanned by a bar code reader to obtain a set of reflected light signals, and then the identified signals are transmitted and processed to obtain the data information stored in the bar code.

There are more than 200 kinds of one-dimensional bar codes in the world with their own unique set of encoding rules. Common one-dimensional bar codes include 39 code, EAN code, UPC code, 128 code, ISBN, ISSN, etc. Since the invention of the UPC code, all sorts of bar code standards and specifications created for different demands have appeared. At present, bar codes have evolved into a vital precondition for commercial automation. Unlike two-dimensional codes, which are mostly used for online goods and Internet information, one-dimensional bar codes remain the dominant form of bar codes used for tangible goods.

### *13.2.3 Two-Dimensional Code Individual Identification Technology*

The two-dimensional code depends on a certain geometric figure to record data symbol in a black and white pattern distributed on a plane surface (in a two-dimensional direction) according to a certain rule. In the coding process, the concept of "0" and "1" bitstreams, which form the internal logic basis of the computer, is used cleverly, and a number of geometrical bodies corresponding to binary are used to represent text numerical information. The technology automatically reads through image input equipment or photoelectric scanning equipment to achieve automatic information processing: on the same unit area, the amount of information stored by two-dimensional codes is nearly a hundred times that of one-dimensional codes. It can store text, pictures, sounds, and other data that can be converted into the digital form. The technology shares some of the common features of bar code technology: each code system has its specific character set; each character occupies a certain width and certain verification functions. At the same time, the technology also features automatic identification of different rows of information and processing graphics rotation changes.

Among the many types of two-dimensional codes, the commonly used codes are: Data Matrix, Maxi Code, Aztec, QR Code, Vericode, PDF417, Ultracode, Code 49, Code 16K, etc. Two-dimensional codes can be divided into stacked/row-type two-dimensional codes and matrix two-dimensional codes. Stacked/row-type two-dimensional codes are built on the basis of one-dimensional codes and are morphologically composed of two or more lines of one-dimensional codes stacked. The matrix two-dimensional code/checkerboard two-dimensional code is composed of a matrix, and the binary "0" and "1" are represented by black and white pixels at corresponding positions in the matrix space. Moreover, the coding is composed of an arrangement of pixels. Some of the commonly used encoding methods include row-type two-dimensional code, Code 49 barcode, Code 16K code, and matrix two-dimensional code.

Two-dimensional codes are widely used in such industries as logistics, agricultural product processing and transportation, security, and traffic management. These are favored due to their unique advantages such as large information storage, low costs, and strong resistance to damage. Meanwhile, owing to the varying characteristics different industries, two-dimensional codes are used in different workflows in different industries. At present, the application of two-dimensional codes in tracing agricultural products is mainly agricultural product processing and logistics. The process is as follows. First, with respect to the entry and verification of raw material information, the supplier of agricultural products enters the raw material production data (origin, production date, shelf life, etc.) into a two-dimensional code and provides the product with the two-dimensional code tag to the buyer. Second, in terms of the entry and verification of production recipe information, one enters the production recipe information (raw material name, weight, ratio, etc.) into a two-dimensional bar code, prints the two-dimensional code tag, and pastes it on the raw material. Third, concerning the entry and query of finished product information, in each inspection process following the input of raw materials, the inspection data is entered using a data collector. At last, the data recorded in the data collector is uploaded to computers to generate the original production data, and this database is used to publish the raw material information of the product on the Internet (Zhou et al. 2012; Fang et al. 2012).

### 13.2.4 Comparison of Two-Dimensional Code and RFID

In recent years, two-dimensional code and RFID technology have emerged as the most widely used tag technologies in the world. It is foreseeable that almost all items in the future will come with a unique two-dimensional code or RFID tag. It is safe to say that tags are the most basic tools for information storage and transmission in IoT, and the telecommunication applications based on the tag technology will be the mainstream application in IoT. Therefore, telecommunications operators must actively promote the migration of label applications to telecommunications networks.

Since its advent in 2004, two-dimensional code has been favored by telecommunications operators in a number of countries for its large data storage, fast and convenient transmission, and strong resistance to damage. Two-dimensional code has achieved universal application worldwide and has become a typical success story of "mobile + tags." Two-dimensional code is extremely convenient for both storing and reading information. On the one hand, the information storage capacity of two-dimensional code is tens to hundreds of times that of the one-dimensional code. Therefore, all the information of a given item can be stored in one two-dimensional code. To view related information, one only needs to scan the code with a reading device without having to establish a database in advance. On the other hand, users only need to install the reading software for free to acquire information through simple code scanning operation. Two-dimensional code is primarily transmitted through packaging, newspapers, books, magazines, products, advertisements, and personal business cards. The major cost of its dissemination is printing fees that do not cost much. Thus, the biggest advantage of two-dimensional codes, like one-dimensional codes, is the ultralow cost.

As a wireless version of the two-dimensional code, RFID represents the future of tag technology. It is considered one of the most promising information technologies in the twenty-first century. RFID, a noncontact writing and reading technology of data, uses radio frequency signals to identify target objects and obtain related data information. Compared with two-dimensional codes, RFID features more advantages.

First of all, RFID is waterproof and antimagnetic. It also features high temperature resistance, long service life, and long reading distance, which means that RFID can work in harsh environments, freeing it from all geographical restrictions. These features are not available in two-dimensional codes and barcodes.

Secondly, RFID makes information identification more intelligent. It allows multiple readings and writings of information. Furthermore, RFID encrypts the single product information stored in the tag and is equipped with larger storage capacity. The RFID tag can store data ranging from 512 bytes to 4M bytes, allowing all items in the world to obtain a unique "identity" like the case in IPv6. At the same time, RFID can record production, transportation, storage, and other related information and identify the machines, animals, and individuals.

Finally, the RFID identification does not require manual intervention, which reduces labor costs. Its operation is convenient and fast, and it can identify objects that are moving at high speed and read multiple tags in batch. Based on these unique advantages, RFID can be extensively adopted in asset management, tracking, logistics, production, transportation, anti-counterfeiting, and any field that demands the collection and processing of information. It can provide information relating to production, transportation, and storage and can identify machines, animals, and individuals. It is safe to draw the conclusion that RFID will serve as the most basic information tool in future IoT.

## 13.3 Agricultural Products Traceability System

### *13.3.1 The Overall Framework*

Food safety relates to public health and safety. The traceability of agricultural products can establish an information database covering all processing stages of agricultural products, ranging from the initial stage to more sophisticated stages. The agricultural product traceability code is the transfer carrier of information, the agricultural product traceability tag is the tangible link of the system, and the agricultural product traceability information management system is used to provide services. Throughout the entire cycle of production, testing, and circulation of agricultural products, the system provides safe production services for producers through the electronic management of production files and offers traceability services to consumers through the information-based detection and circulation of pesticide residue. Additionally, the system also builds platforms for data integration, query, analysis, and early warning for the supervision by the trading center. Consumers can check the relevant food information at any time to ensure food safety. The system creates a smart agriculture to ensure the safety and credibility of agricultural products and establishes a traceability information database for production and circulation. Apart from this, it also conducts full-process monitoring and management of each link, carries out comprehensive analysis and utilization of traceability information, and provides a platform for information traceability. In addition, comprehensive information services are provided through such channels as the Internet and clients. The traceability system is characterized by early warning of safety, traceability at source, traceability of flow direction, information inquiry, determination of accountability, and the ability to retrieve products.

A flowchart of the traceability of agricultural products is shown in Fig. 13.4. During the production and harvesting stage, agricultural products are assigned with batch numbers through traceability information and then enter storage and circulation, which is called entering the market. After entering the market, the relevant node data is entered into the agricultural product circulation supervision system, and the circulation traceability information is written on the basis of the original

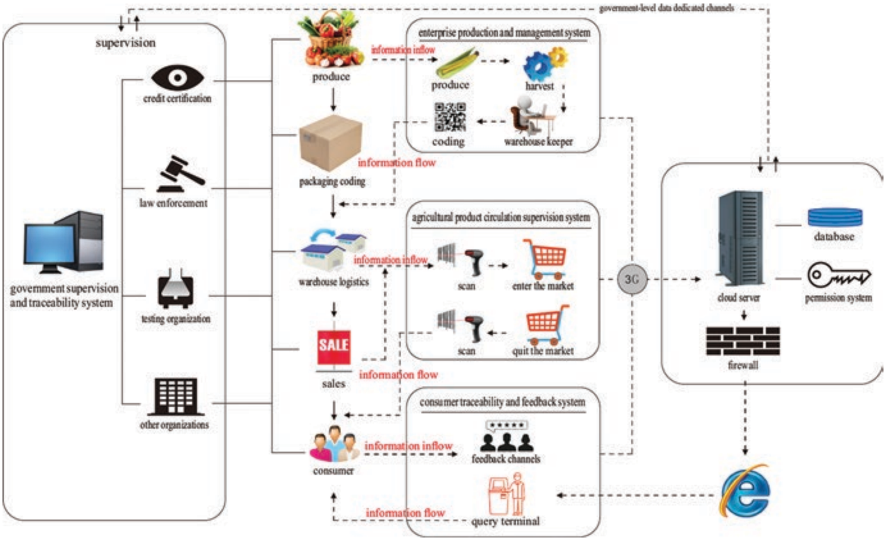


**Fig. 13.4** Agricultural products traceability flowchart

production information. After sales, the products reach the consumers and exit the market. At this time, consumers can scan the two-dimensional code to acquire the source information. They may also voice their feedback and complaints according to consumer experience. The government and inspection department could tap into the data with the traceable cloud server through a dedicated data channel, hence achieving transparent supervision of the entire process of agricultural products from the field to the dining table.

The traceability system should be led and managed by the government to transparently supervise the production and distribution nodes of agricultural products. In addition, third-party organizations, such as quality inspection agencies, ought to conduct random sampling inspections of agricultural products at various nodes, and industry associations must supervise agricultural production enterprises. At the same time, consumers voice their feedback and complaints about products. All this information will be incorporated into the corporate credit system to keep consumers informed and to protect their legitimate rights and interests.

Different business entities can manage and acquire the source tracing information according to the principle of rights distribution. For example, consumers can only acquire the specified basic source tracing information and cannot acquire technical and confidential information such as the company's production process. The government, on the other hand, has certain authority to supervise the information of enterprise production process nodes.

The agricultural product traceability information database mainly includes information on production, purchase and transaction, processing, logistics, retail, and traceability websites.

### *13.3.2 Agricultural Product Traceability Information Management*

#### 13.3.2.1 Production Information Management

During planting, information, such as seed and fertilizer purchase, sowing, irrigation, fertilization, picking, and testing, are collected and monitored according to different batch numbers, thus facilitating the traceability management of planting information. Meanwhile, IoT technology in agriculture is adopted to build smart agriculture and to obtain information about plant growth environment, such as temperature, humidity, light intensity, plant nutrient content, and other parameters. Such adoption enables the acquisition, management, display, and analysis of information of all base test points and achieves automatic control and management of operations.

During the processes involved in livestock farming, relevant data that must be recorded include the source of livestock (cattle, sheep, etc.) seedlings, information on commercial livestock (cattle, sheep, etc.), immunization, diagnosis and treatment, purchase and use of veterinary drugs, purchase and use of feed or additives, disinfection, death treatment, monthly production report, operator, etc. It is critical to formulate a corresponding system and strictly follow the specifications for production, and each base must be connected to the Internet or home broadband (for video surveillance). Online environmental monitoring and management systems can be installed in farms, and sensing equipment can be relied on to monitor the temperature, humidity, and air quality in livestock (cattle, sheep, etc.) farms and to give early warnings.

The importance of environment and water quality monitoring in aquaculture is self-evident. The production process is highly demanding with respect to a number of factors that include water quality, dissolved oxygen, water temperature, feed, climate, light, and biology. Effective monitoring and recording of these factors are essential to traceability of aquatic product quality. Using automatic detection and control technology, technicians can achieve accurate online monitoring of changes in water quality values, dissolved oxygen, water temperature, and water depth through various sensors.

#### 13.3.2.2 Purchase and Transaction Information Management

The IoT system for the purchase and transaction of agricultural products aims to achieve data collection and product quality control management in the procurement process using modern information technologies such as RFID, RFID read-write equipment, Internet, wireless communication networks, 3G, IPV6, and intelligent control. It is the initial link of the information management for the entire chain of agricultural product logistics.

**Production of Electronic Tags and Data Upload**

Electronic tags of the products produced by the production base (the products purchased by the purchasing department) made before the products are packed, and the related product information is transmitted to the database of the system server through the network via handheld RFID card readers or intelligent mobile read-write devices. This marks the start of the whole process of circulation management and tracking. The related product information mainly includes the product name, origin, quantity, size of the warehouse, estimated arrival time, etc. Processing operations are then carried out on the data server of the IoT, so that preparation and coordination of the cold storage for the distribution headquarters can be effectively managed.

**Management of Purchase Orders**

Purchase orders are generated mainly relying on inventory information and customer orders, and management of purchase orders is achieved. Such functions are enabled by RFID, RFID read-write equipment, mobile RFID read-write equipment, wireless communication network, Internet network, computer, etc.

#### 13.3.2.3 Processing and Warehouse Logistics Information Management

From the arrival of agricultural products to the factory and to inspection and processing, the entire process is tracked, and related information is collected according to each batch number. Each processed product will be assigned a two-dimensional code for the corresponding batch number and an RFID agricultural product identification mark. During the processing of agricultural products, the perception layer mainly works through two-dimensional codes, acquisition of RFID agricultural product identification information, and processing environment monitoring.

Concerning market circulation, real-time monitoring of environmental information during warehousing and logistics can avoid quality disputes after the products are sold (Fig. 13.5). This IoT system can quickly locate the node information where quality problems occur. While protecting the interests of businesses, the system can also issue prompt warnings of quality and safety information. In terms of product identification and traceability in agricultural product logistics, RFID technology and barcode automatic identification technology are often used, whereas in transportation positioning and tracking, GPS positioning technology, RFID technology, and onboard video recognition technology are frequently used. Additionally, regarding quality control and status perception, sensor technology (temperature, humidity, etc.), RFID technology, and GPS technology are favored.

**Perception Layer of Agricultural Product Logistics IoT**

The perception layer mainly includes sensor technology, RFID (radio frequency identification) technology, two-dimensional code technology, multimedia (video, image acquisition, audio, text) technology, etc. The perception layer, mainly used to identify objects and collect information, bears similarities with the role of skin and facial features of man. In the circulation of agricultural products, it identifies and

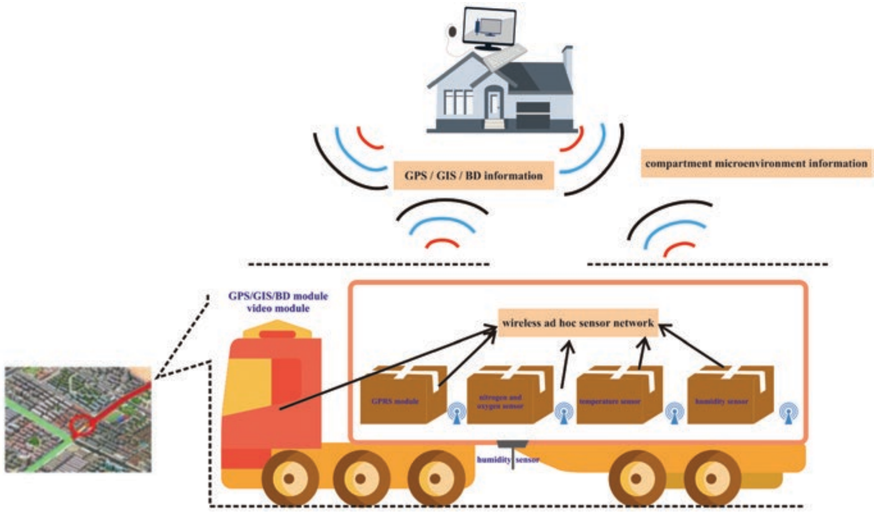


**Fig. 13.5** Logistics environment monitoring

collects the relevant information of agricultural products during the entire circulation.

**Transport Layer of Agricultural Product Logistics IoT**
The network layer includes a converged network of communications and the Internet, a network governance center, an information center, and an intelligent processing center. The network layer, transmitting and processing the information obtained by the perception layer, is similar to the nerve center and brain of man. The information system for agricultural product logistics management and operation in certain areas tends to rely on the company's internal LAN technology and interfaces with the Internet and wireless networks. In places where wiring is not convenient, wireless local area networks are often used. The combination of Internet technology and GPS technology is often adopted in large-scale agricultural product logistics transportation management and dispatching information systems. In the logistics center information system with storage as the core, network technologies, such as fieldbus technology, wireless local area network technology, and local area network technology, are relied on, while in network communication, wireless mobile 356 communication technology, 3G technology, and M2M technology are the major components.

**Application Layer of Agricultural Product Logistics IoT**
The application layer is the deep integration of the IoT technology and industry expertise. Through the combination of the IoT technology and the industry needs to achieve the industry intelligence. The application layer is charged with three tasks: one, carrying out cloud-based processing, such as the acquisition and storage of information for agricultural products circulation IoT; two, providing IoT cloud services in the purchasing, allocation, and transportation; and three, offering cloud

services on circulation information. The application layer constructs agricultural product logistics information cloud processing system, electronic transaction information cloud service system, distribution information cloud service system, transportation information cloud service system, and agricultural product circulation information service system. Additionally, it develops and integrates the cloud computing resources of the agricultural product logistics IoT and establishes the agricultural product logistics IoT cloud computing environment and application technology system. Cloud computing capabilities, storage space, data knowledge, model resources, application platforms, and software services are provided at the application layer. Moreover, the application layer works to improve the collection, management, sharing, and analysis of agricultural product logistics information. It brings together different factors of agricultural product circulation and allows different pieces of information to converge. Relying on the application layer, the rapid formation and expansion of the industry chain of agricultural product logistics could be achieved.

## 13.4 Application of Production Traceability Using IoT Technology

### *13.4.1 Traceability of Crop Production Information*

#### 13.4.1.1 Crop Farming Traceability System

The traceability of crop farming covers the production, circulation, and marketing of crops. Figure 13.6 illustrates a functional structure of IoT-based crop production traceability. There are two functional modules in production, including the agricultural product production records management module and the agricultural product environmental information detection module. The former can achieve the record management of fertilizer and water operations, plant protection operations, and other agricultural operations in the agricultural product production process. The latter, through different sensors, enables the automatic collection of such data as air temperature and humidity, carbon dioxide concentration and soil moisture, fertility, and heavy metal content. In circulation, real-time monitoring of environmental information during warehousing and logistics processes is used to forestall quality disputes. Through monitoring, quality-related problems will be identified as soon as possible. While protecting the interests of businesses, the system can also issue early warnings of quality and safety information. After agricultural products enter circulation, the comprehensive management of licenses, operating records, and purchase and sales vouchers of each node effectively eliminates the blind spots on the circulation chain. After the products enter the market, consumers can trace the source relying on the two-dimensional code, batch number, query code, and so on.

The traceability system, centered on the field production records, achieves comprehensive management of agricultural production processes, including the names

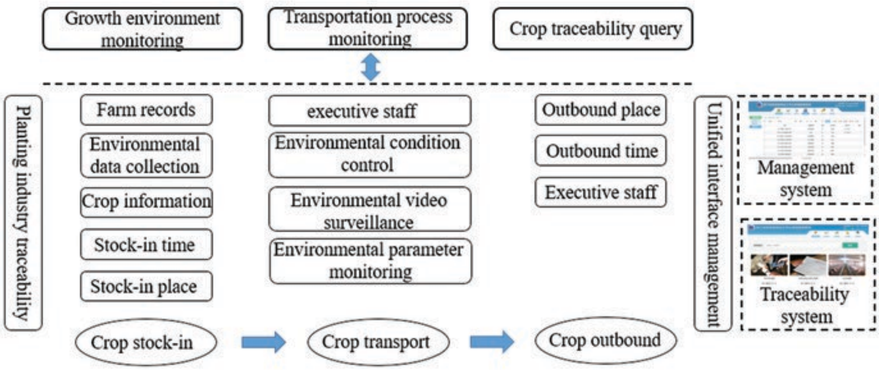


**Fig. 13.6** Functional structure of IoT-based crop production traceability

of agricultural inputs, fertilizing, spraying, detecting, and harvesting operations. The farming information records include the following aspects:

- Fertilizer and water operation information record, including fertilizer types, ingredients, fertilization time, manufacturer information, the duration and frequency of irrigation, area water consumption, etc.
- Plant protection operation information record, including spraying time, pesticide types, object of prevention, spraying frequency, pesticide dosage, etc.
- Farm operation and management information record, including crop variety, cultivation region, harvesting, and other operation information

The system can also collect the growth environment parameters (including weather, altitude, soil fertility, and other information) in real time via IoT networks at different stages of agricultural product production and draw historical curve charts for query. Environmental data collection mainly includes the following aspects:

- General parameters are collected by various sensors, including air temperature and humidity, soil temperature and humidity, illumination intensity, carbon dioxide, ammonia nitrogen, etc.
- Meteorological parameters are collected by meteorological stations, including air pressure, temperature, humidity, wind speed, precipitation, etc.
- Soil information is collected by detection equipment, including soil fertility, heavy metals, soil structure, etc.

Real-time monitoring and early warning of the environment during the warehousing and transportation of agricultural products can minimize the loss and quality problems caused by the storage and logistics environment and are conducive to the monitoring of product quality. System functions include:

- Warehousing and logistics environment monitoring: general parameters, including cabin temperature and humidity, are measured by sensors; video surveillance is achieved using an infrared dome camera; and position information is obtained by the GPS module.

- Basic function parameters, including basic information of warehousing and logistics, acceptance handover management, and report form management.

When the agricultural products enter circulation, if only the producers and consumers are involved, the difficulty of tracing is relatively low, but in fact, after the agricultural products leave the production base, there are a large number of circulation points, and the supervision is quite challenging. Therefore, a circulation information monitoring module is needed to comprehensively monitor and manage the channels, routes, and nodes that agricultural products pass through from production to consumption, thus eliminating the blind spots in circulation. The comprehensive management of each node includes the operator's archives, product quality control (variety, quality inspection, and so on), purchase certificate, records and sales vouchers, and other types of information.

When agricultural products are purchased, consumers can trace the source using the two-dimensional code, batch number, query code, etc. The query channels mainly include Internet portal (Web), query machine (Web), mobile bar code access (Web), short message service (SMS), interactive voice response (IVR), and other methods (such as WeChat, Yixin). The content of the query primarily covers information on origin, production, quality inspection, logistics and storage, quality standards, etc. (Fig. 13.7).


**Fig. 13.7** Traceability query results page

#### 13.4.1.2 Application of Farming Product Traceability System

Liu et al. (2014) constructed a RFID-based vegetable safety traceability system based on the actual management scenarios of the inspection department. The system includes business framework module, technical framework module, and safety guarantee system module. Furthermore, it also covers the functional demands of vegetable planting bases, vegetable processing factories, and vegetable import and export ports and sales points, and interface standards are formulated for the traceability system. The results of operation demonstrated that the traceability system is reliable and effective. The focus on food safety problems in fruit and vegetable planting and processing is concentrated on the detection of pesticide residues. This approach can achieve monitoring, yet it fails to eliminate the hidden dangers from the source. The application of RFID technology has fulfilled this demand, and the food safety control of fruits and vegetables will further improve with the support of relevant regulations.

Shen (2017) made thorough use of network technologies, such as RFID, to build a cold chain logistics traceability system for fruits and vegetables. The system was distributed and managed in the form of subsystems, including subsystems of fruit and vegetable production, wholesale, logistics, sales, supervision, inspection, and retrospective inquiry. Each subsystem had a corresponding information database, and the functions of the subsystem also work independently. The system relies on codes to identify all processes relating to fruits and vegetables from the place of production to consumption, thus making the traceability information complete.

Based on RFID technology, Jiang (2017) established a tea quality and safety traceability system. The first working process of the system is to place RFID tags in the tea farms for collecting and recording information on fertilization, pest severity, pesticide, spraying time, climate conditions, and so on and then upload the information to the information processing center of traceability system. The second process is the processing of fresh leaves after picking, and the collected information include the source of the tea, the name of the company that processed the fresh leaves, and the main technical parameters of processing. The third process relates to packaging and finished products. In addition to collecting general packaging information, a close relationship is established between the RFID tag of the finished products and the RFID tag of the tea farms to facilitate traceability by consumers. The fourth process covers all the relevant information and data on the storage, logistics, and sales of tea products. Due to the unique characteristic of RFID tag, one only needs to bind the ID number to the data of the circulation processes of tea to achieve traceability.

## 13.4.2 Livestock Farming

Livestock farming, a typical process-based manufacturing industry, is characterized by the fact that the products, once produced, cannot be reversed. The safety management of products in livestock farming may encounter problems in all processes, including production, processing, storage, transportation, and sales. In recent years, food safety incidents have repeatedly occurred, causing panics among the general public. Therefore, information-based product safety has become a key part of food safety supervision. Using information technology to improve the quality and safety of animal products and production has emerged as a major issue for the government, academia, and the public.

### 13.4.2.1 Quality and Safety Traceability System for Products in Livestock Farming

The goal of this traceability system is to achieve the supervision of product information along the entire production chain, from breeding to market sale, and to realize accurate inquiry of products. The processes mainly include breeding, quarantine, verification and inspection, the period before slaughtered, slaughtering, sales, slaughterhouse to market, and backtracking.

**Architecture Design of the Traceability System (Fig. 13.8)**

**Process Design of the Traceability System**

During the whole process of meat production, processing, warehousing, and logistics, RFID tags are first used to identify the relevant information of the primary processed products (Fig. 13.9). At this time, the individual production information of the products is stored in the database, with the RIFD as the identification number. During the processing process, two-dimensional codes are used to identify processed products. Taking pork as an example, during the production process, RFID tags are used for individual identification and marking of pigs, and feeding information, health status, and growing environment information are all recorded and stored in the ID number identified by RFID. During processing, a pig will be processed into several packages of pork products. Meanwhile, two-dimensional codes containing pork-related information are printed on the pork packaging boxes, i.e., each package is identified and tracked in the form of a two-dimensional code. The relationship between the two-dimensional code and RFID is many-to-one, associating production with processing. During transportation, the two-dimensional code will store and track the information of each product until the pork is sold to the consumer. Consumers can scan the two-dimensional code through mobile phones and smart terminals to get access to the information of the corresponding pork products from the network.

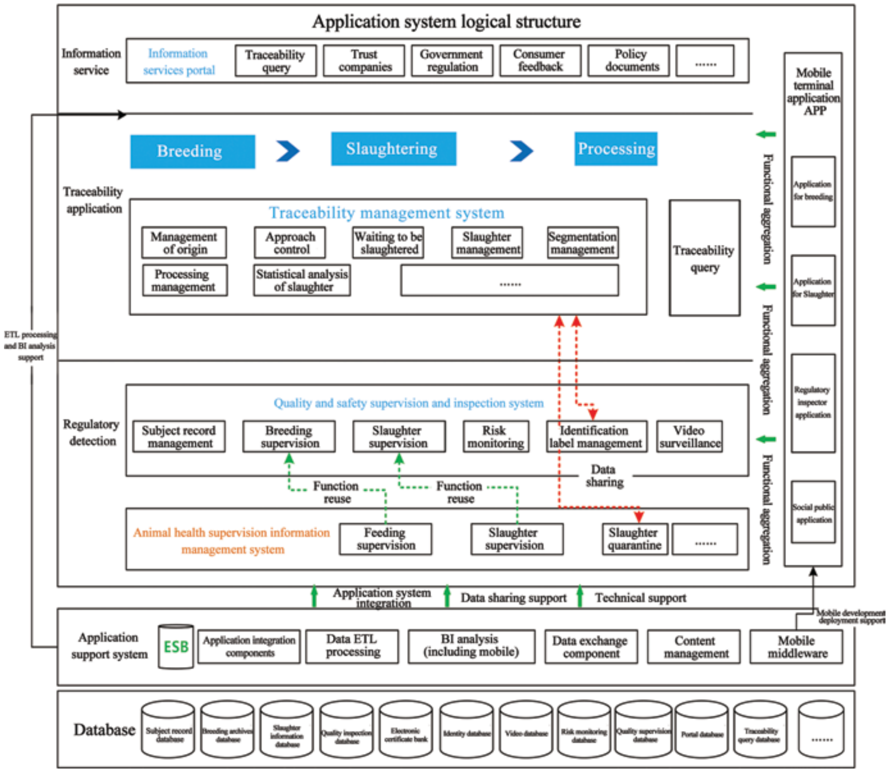


**Fig. 13.8** Overall architecture of the traceability system

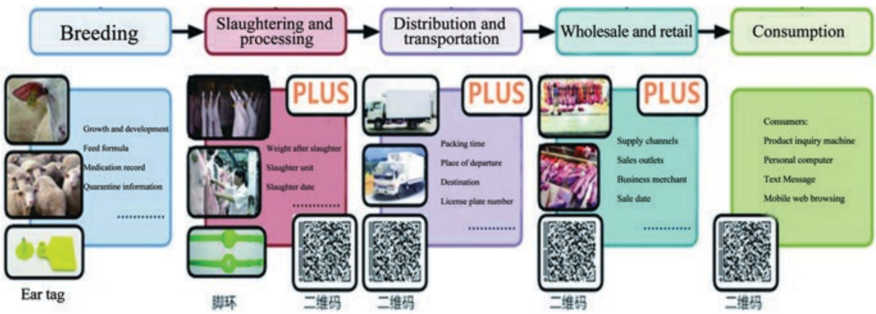


**Fig. 13.9** The information flow and traceability process

### 13.4.2.2 Traceability Application of Products in Livestock Farming

In October 2010, the Ministry of Commerce of China announced the pilot project to construct traceability system of meat and vegetables in large- and medium-sized cities nationwide. Chengdu was one of the first ten pilot cities. At present, Chengdu's meat and vegetable circulation traceability system covers more than 10,000 points of sale. Let us take the pork traceability system as an example; citizens can trace detailed information via the system, covering wholesalers, slaughtering companies, slaughtering time, meat inspections, animal inspections, pig suppliers, origin of pigs, origin quarantine number, and license plate numbers of transport vehicles.

RFID technology in IoT is widely used as it is simple and practical, and as such, it can quickly respond to food safety management, trace the source, determine problems, and enable effectively control. Song (2014) designed a pork safety traceability management system based on RFID and used RFID tags as the main way to collect information, while taking into consideration the actual production environment of pork. The results demonstrated that through sensing and RFID technology, the production process of pork can be accurately tracked, and the goal of safe and accurate traceability of pork can be achieved. Zhang (2017) combined RFID and NFC technology to collect information in the process of lamb slaughtering and processing and mainly collected information on seven key nodes of this process to achieve traceability of lamb quality and safety in Xinjiang.

## *13.4.3 Aquaculture Industry*

China is a major country in the production, export, and consumption of aquatic products. As the proportion of aquatic products consumption in food consumption gradually increases, the quality and safety of aquatic products have entered into the spotlight. At present, the foundation of China's aquatic product quality and safety remains weak compared to developed countries, and the key issues affecting the quality and safety of aquatic products have not been addressed. Therefore, there are still many hidden dangers to the quality, sanitation, and safety of aquatic product, and the quality and safety issues of aquatic products remain salient. Such problems as excessive hygiene standards, excessive or illegal use of additives, irregular packaging of aquatic products, fraudulent labels used to deceive customers, adulteration, shoddy products, and artificial water injection have not been restricted. Quality and safety issues of aquatic products exert a negative impact on public health, social stability, and China's international image and cause severe economic losses. Therefore, strengthening the quality and safety management of aquatic products is the key to ensuring the sustainable development of aquaculture. In particular, production records, the traceability of product flow, and the traceability of product quality ought to be made available to the general public.

### 13.4.3.1 Aquaculture Safety Traceability System

Figure 13.10 illustrates the information flow in the aquaculture traceability system. The aquaculture safety traceability system first relies on both automatic information collection and manual collection to record information into the database as the

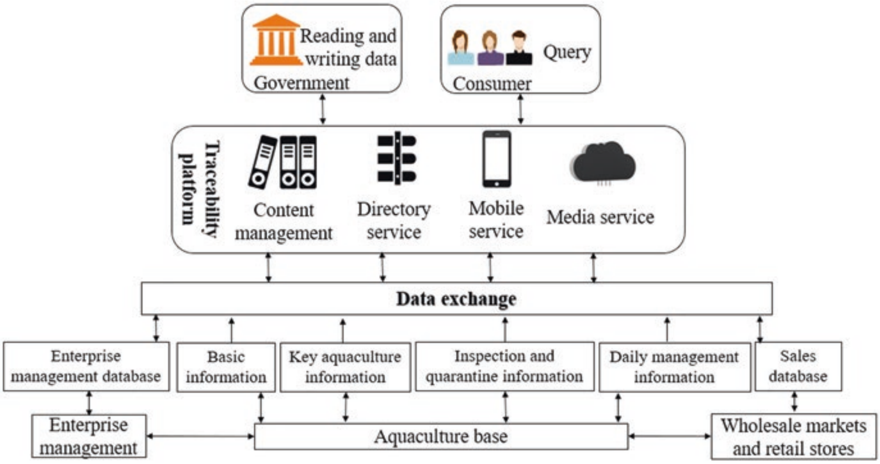


**Fig. 13.10** IoT-based aquaculture safety traceability information flow

original data for quality traceability. The key of quality and safety control in aquaculture is that the information collected ought to be factors that are closely related to the safety of aquatic products, including basic information, key aquaculture information, inspection and quarantine information, and daily management information.

Basic information is the static information used to describe the basic attributes of aquatic products, including aquatic product types, origin, name, and meteorological information of the origin.

Key information in the breeding process mainly includes information on seedling, feed, drug, and water quality. The seedling information includes basic information, drug residue information (pesticides, veterinary drugs), and information on heavy metals, microbial indicators, and virus; feed information includes basic feed information, storage information, and use information; drug information includes basic information, storage information, and usage information; and water quality information includes routine, microbiological, and heavy metal information (Zhang 2016).

With respect to the inspection and quarantine information, the detection of aquatic products is a key to ensuring the safety and quality of aquatic products. This process includes detection along the aquatic product supply chain, covering the seedlings, breeding, delivery, sales, and so on, and the information so acquired are then sent to the database. The detection includes water quality detection and drug residue detection.

Daily management information. In aquaculture, a number needs to be configured for each breeding cage as the unique identification certificate for the two-dimensional code. The daily management and the feed and drug are recorded with the two-dimensional code label, the carrier, the breeding cage, and the unit. At the same time, each bag of feed and drug adopts a two-dimensional code label as a unique

**Table 13.1** Classification of traceability information

| Category | Data content | Data source | Update frequency | Openness |
|---|---|---|---|---|
| Basic information | Types of aquatic products, origin, name, meteorological information (temperature, precipitation, wind speed, etc.) | Production enterprises, meteorological departments | Fixed-point monitoring, real-time update | Open to the public |
| Key information in the process | Seedling, feed, medicine, water quality, culture pond | Production enterprises | Real-time update | Open to the public |
| Inspection and quarantine information | Seedling, aquaculture, factory and sales | Inspection and quarantine department | Real-time update | Inter-departmental opening |
| Daily management information | Remote pond management, feed and drug use | Production enterprises | Real-time update | Inter-departmental opening |

identity, which records purchase information and usage information. Table 13.1 is an illustration of the classification of specific traceability information.

The general supply chain of aquatic products is farms → aquatic products enterprises → aquatic products wholesaler → aquatic product retailer → consumers. The traceability system ensures the accuracy of the information of aquatic products in all processes along the logistics chain. Figure 13.11 offers an illustration of the complete traceability system of aquatic products. Horizontally, it consists of the supervisory and traceability system, production management system, transaction management system, and traceability information query system. Vertically, it consists of the supervisory body, responsible body, information transmission, and product circulation.

The regulatory bodies, including national regulatory platforms and local regulatory platforms, are responsible for the formulation of some rules. They are also charged with the task of publishing product information to consumers and receiving consumer complaints and feedback. The responsibility body means that the enterprise is responsible for the aquatic products cultured and purchased. Wholesalers must purchase products legally using the legal identity of the enterprise, and at the same time, the farmers' market must ensure that only valid aquatic products can enter into the market according to the effective barcode printed by the enterprise. Aquatic products and related information are distributed alongside two-dimensional codes and receipts, ensuring the safe flow of products. The traceability labels of product quality and safety clearly record the product name, batch number, transaction date and quantity, aquatic product company name, and traceability number, and the ciphertext records each breeding indicator. Once a safety accident occurs, the cause of the accident can be accurately identified.

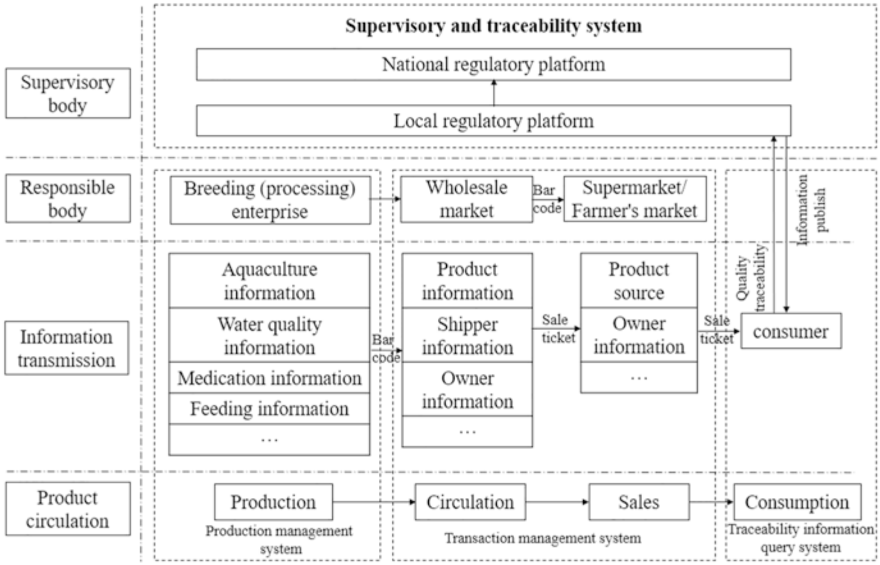


**Fig. 13.11** Aquatic product traceability IoT system framework

#### 13.4.3.2 Application Examples of Aquatic Traceability

As a major aquaculture province, Jiangsu has set up retrospective supervision subcenters in more than ten aquaculture departments in the province. The province established a three-level management system of "provincial center to subcenter to traceability point" and a variety of aquatic product quality traceability models. A four-in-one framework for the aquatic product quality and safety traceability has been established, including "aquatic product quality and safety traceability, online monitoring of water quality, remote diagnosis and treatment of aquatic animal diseases, and aquaculture environmental supervision." Using digital barcode and two-dimensional code technology, digital connection of water quality management, farmers, production place, feeding, medication, and other information in the aquaculture production process is achieved (Huang and Wu 2014). Jiangsu Province has initially achieved traceability of the source and destination of aquatic products, and accountability for safety issues can be investigated.

In relation to the short-range object recognition technology, Yan et al. (2013), taking tilapia as the research object, designed and developed a type of IoT based on radio frequency identification and product electronic code, including five subsystems: breeding management system, processing management system, distribution management system, sales management system, and inquiry supervision system. Zhang (2016) designed an aquaculture safety traceability system based on multi-information fusion. The system provides reference data for aquaculture health through fusion and analysis of multisource information. Regarding the complex tracing problems caused by aquatic products in ponds, a tracing algorithm based on two-dimensional codes is proposed – tapping into the idea of collection and recursion to connect aquatic information flow and to ensure the integrity of tracing information.

## 13.5 Summary

Problems of agricultural products in any process, from production to sale, may cause food safety problems. Traceability systems of agricultural products can monitor the information of the whole production process, providing an effective way for food safety management. This chapter laid an introduction of the application of the IoT technology in traceability systems of agricultural products, covering the key technology, system structure, and specific applications. It is demonstrated that the development of the IoT technology drives food safety forward. In particular, it is shown that the development of information sensing technology makes the information collection more comprehensive. There is still a trust crisis in the current food traceability system, and the best solution is to make use of blockchain technologies to integrate the data of key links in agricultural production, circulation, and sales, thus bringing about a seamless convergence between blockchain technology and IoT technology. In agricultural production of the future, all products will have their own identities, and the agricultural IoT technology will penetrate into all aspects of agriculture. Through the network, people are able to acquire various information on the production, processing, and logistics of agricultural products.

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