IEEE Access
Multidisciplinary ⋮ Rapid Review ⋮ Open Access Journal

Received April 13, 2021, accepted April 29, 2021, date of publication May 10, 2021, date of current version May 18, 2021.

Digital Object Identifier 10.1109/ACCESS.2021.3078536

Construct Food Safety Traceability System for People's Health Under the Internet of Things and Big Data

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This work was supported in part by the Research Fund for Young Doctoral Scientist of Harbin University: Research on Synergistic Mechanism of Compound Enzymatic Method in Waste Paper Deinking, Harbin University, under Grant HUDF2019103, in part by the Postdoctoral Research Fund of Heilongjiang Province: Isolation and identification of strain producing compound enzyme deinking and its application in waste paper deinking, Science and Technology Department of Heilongjiang Province, under Grant LBH-Z18028, in part by the National Innovation and Entrepreneurship Training Program for College Students Supported by: Education Department of Heilongjiang Province, Analysis of Soybean Rhizosphere Microflora and Study on Effect of Biological Fungi Fertilizer, under Grant 201910234015, and in part by the National Innovation and Entrepreneurship Training Program for College Students Supported Project: Education Department of Heilongjiang Province, Research on the Application Mechanism of Microbial Lipase in Facial Cleansing Milk, under Grant 201910234018.

ABSTRACT In the context of epidemic prevention and control, food safety monitoring, data analysis and food safety traceability have become more important. At the same time, the most important reason for food safety issues is incomplete, opaque, and asymmetric information. The most fundamental way to solve these problems is to do a good job of traceability, and establish a reasonable and reliable food safety traceability system. The traceability system is currently an important means to ensure food quality and safety and solve the crisis of trust between consumers and the market. Research on food safety traceability systems based on big data, artificial intelligence and the Internet of Things provides ideas and methods to solve the problems of low credibility and difficult data storage in the application of traditional traceability systems. Therefore, this research takes rice as an example and proposes a food safety traceability system based on RFID two-dimensional code technology and big data storage technology in the Internet of Things. This article applies RFID technology to the entire system by analyzing the requirements of the system, designing the system database and database tables, encoding the two-dimensional code and generating the design for information entry. Using RFID radio frequency technology and the data storage function in big data to obtain information in the food production process. Finally, the whole process of food production information can be traced through the design of dynamic query platform and mobile terminal. In this research, the food safety traceability system based on big data and the Internet of Things guarantees the integrity, reliability and safety of traceability information from a technical level. This is an effective solution for enhancing the credibility of traceability information, ensuring the integrity of information, and optimizing the data storage structure.

INDEX TERMS Two-dimensional code technology, Internet of Things, big data, artificial intelligence, food safety traceability system.

I. INTRODUCTION

As the global new crown virus (COVID-19) epidemic intensifies, there are more and more cases of COVID-19 spreading through cold chain logistics channels. COVID-19 has become the most important source of hazards to food safety in the cold chain logistics process. Although the overall prevention and control situation of our country's new coronavirus pneumonia epidemic continues to improve, the accelerated spread of the overseas epidemic has led to the domestic epidemic prevention situation of ''foreign import and internal prevention'' is still severe. In the context of epidemic prevention and control, food safety monitoring, data analysis, and food safety traceability have become more important.

The associate editor coordinating the review of this manuscript and approving it for publication was M. Shamim Hossain.

Especially for cold chain food imported from overseas, every food should be monitored and traced to prevent the spread of COVID-19 virus and protect the health and safety of the population. Therefore, the establishment of a safe and reliable food safety traceability management system is an urgent requirement of the society and the people, and it is also an effective way to fundamentally solve the post-epidemic era and protect the health of the population. The food safety traceability management system is based on automatic identification and information technology to integrate information in the entire chain of food production, processing, storage, transportation and sales. A comprehensive service management platform that is presented to users and consumers in real time through the Internet, terminals, phone calls, and text messages. At the same time, the food safety traceability system involves food planting (breeding) purchase links, enterprise processing (packaging) links, storage and logistics links, and sales links [1], [2]. Through the information traceability mechanism, the responsible body of each link of food production and circulation can be clarified, so as to more effectively control the safety and reliability of breeding (planting), processing, and transportation, and indeed prevent various food safety risks, and protect the people's safety and health.

The development of automatic information generation equipment represented by sensors and intelligent terminal recognition has enabled rapid development of technologies such as perception, measurement and monitoring based on the Internet of Things (IoT), artificial intelligence and big data technology. The Internet of Things and big data technology are profoundly changing people's production and life, and their significance has gone beyond the scope of communication technology [3]. The Internet of Things is the use of information technologies such as the Internet and sensors to connect people and things together, so that things can be interconnected, forming a new network of intelligent sharing of information. Artificial intelligence has the huge advantage of simplifying the process of using data, and it could play a huge role in areas such as food safety. Big data technology is a data processing and application model based on cloud computing and distributed computing. It can realize accurate prediction or analysis through the integration and sharing of data and the application of reasonable mathematical algorithms. In food traceability, the successful application of big data needs to be combined with technologies such as automatic identification and network communication, these five main links play a role through data capture, data storage, data processing, data mining, and data knowledge display. Big data realizes the aggregation and virtual management of data, optimizes the allocation of information resources, which is conducive to the realization of cross-regional and cross-domain supervision that is difficult to break through in real management. In recent years, big data has been widely used in the agricultural industry and has become an important force in promoting the transformation of traditional agriculture. At the same time, since food quality is closely related to all links of production and circulation, the construction of a food quality and safety traceability system must receive strong support and mutual cooperation from upstream and downstream related companies. Using the Internet of Things technology to build a food safety traceability system will greatly reduce the difficulty of collaboration. In this context, information technology is used to carry out food safety traceability in the context of post-epidemic situations, and IoT and big data technologies are applied to the food safety traceability management system in the post-epidemic era [4]. Ensuring food safety in the whole process of food production, inventory, distribution and sales has become a hot research issue in the field of food safety for people's health.

Therefore, this research proposed a food safety traceability system based on RFID technology and big data storage technology in the Internet of Things. The use of the Internet of Things and big data technology has realized the data collection of various food data. The use of RFID technology to realize automatic recording of relevant parameters avoids the contamination of food product traceability information caused by manual data input. At the same time, a set of small food industry data search engine was designed and implemented by using big data analysis technology. The traditional traceability system is integrated with the Internet of Things and big data technology to realize the traceability of the entire agricultural production process of agricultural and sideline products such as planting, processing, testing, warehousing, transportation, and sales. This ensured that the source of agricultural and sideline products can be traced, flow can be traced, information can be inquired, and responsibilities can be held accountable to protect people's health and food safety. The food safety traceability system constructed in this research has a perceivable realization process, traceability of the source, and early warning of risks. This is of great significance for improving the management level of China's food quality and safety, preventing food safety accidents, maintaining the balance of supply and demand, and ensuring people's health and safety.

II. ANALYSIS OF THE KEY TECHNOLOGIES AND ADVANTAGES OF THE INTERNET OF THINGS AND BIG DATA IN THE FOOD SAFETY TRACEABILITY SYSTEM

A. THE KEY TECHNOLOGIES USED BY THE INTERNET OF THINGS AND BIG DATA IN THE FOOD SAFETY TRACEABILITY SYSTEM

The technology of the Internet of Things mainly relies on communication and perception technology, which can be widely used in modern production and life. The Internet of Things can be regarded as a product of the organic combination of sensor networks, the Internet, and mobile networks. It can be divided into a perception layer, a network layer, and an application layer, with sensor network technology as the core. The successful application of big data needs to be combined with technologies such as automatic identification and network communication. It plays a role through five main

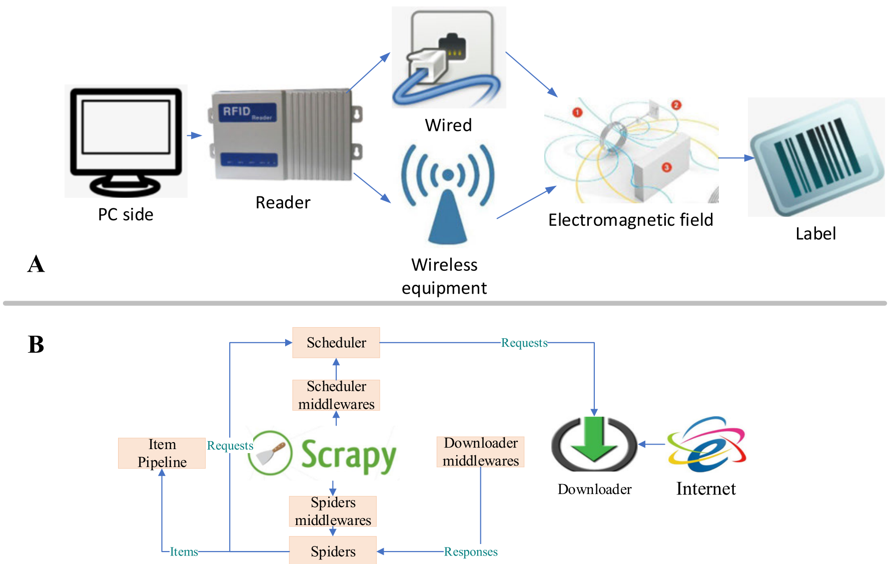

FIGURE 1. **The principle of RFID radio frequency technology (A) and scrapy crawler architecture diagram(B).**

links: data capture, data storage, data processing, data mining, and data knowledge display [5]. Combined with the analysis of the requirements and characteristics of the food safety traceability system, the following technologies can be used in the Internet of Things and big data technologies [6].

1) INDIVIDUAL AUTOMATIC IDENTIFICATION TECHNOLOGY

The automatic identification technology of food labeling uses computers and related software and hardware to encode, identify, collect, input and output individual food labels that need to be traced. These processes are all carried out automatically. The radio frequency identification (RFID) in the individual identification technology is a technology that can remotely identify a target object without direct contact and collect relevant information. Combined with an effective database system and network system, the tracking and information sharing of items on a global scale can be realized. The principle is shown in Figure 1A. 2-Dimensional barcode technology is one of the automatic identification technologies for individuals. Using the concept of "0" and "1" bit streams that constitute the internal logic of the computer, it can be automatically read through image input electronic equipment or through photoelectric scanning equipment to realize automatic processing of information, thereby achieving one-to-one tracking and Traceability.

2) SENSORS AND WIRELESS DATA TRANSMISSION

Sensors belong to the nerve endings of the Internet of Things, and become the core components for humans to fully perceive nature. The large-scale deployment and application of various sensors is an indispensable basic condition for the Internet of Things. The wireless data transmission selected in this research is mainly through ZigBee technology, which is a short-distance, low-complexity, low-power, low-rate, low-cost two-way wireless communication technology [7]. It is mainly used for data transmission between various electronic devices with short distances, low power consumption and low transmission rates.

3) PYTHON PROGRAMMING LANGUAGE

In the process of using the Python language, functions or other information are written into the *.py* file and compiled into bytecode by the Python interpreter. Finally, it is handed over to the Python virtual machine for execution. Usually, the compiled bytecode file is in the format of *.pyc*. In addition, Python can be directly interactively operated on mainstream operating systems such as Linux, windows and MAC, making development and debugging easier.

4) SCRAPY CRAWLER FRAMEWORK

Scrapy is an open sources Internet crawler framework based on the Python language. It has the characteristics of complete functions, low development difficulty, and extremely strong expandability. Scrapy uses the Twisted network asynchronous framework to process network requests. The overall working architecture is shown in Figure 1B. The main workflow of Scrapy is that Spider assigns the first page to be visited to the engine, and the engine is processed by the scheduler for sorting; The engine obtains a page link from the scheduler, encapsulates it as a Request and sends it to the downloader for download; The downloader encapsulates the web content processing into a Response and sends it to the crawler for processing; The crawler parses the Response, encapsulates the first data processing into an Item, and obtains several links that need to be visited in the next step. Item is handed over to the Pipeline for one-step processing, and the link is handed over to the engine for processing; Entity data is circulated to the pipeline for further data cleaning and persistence

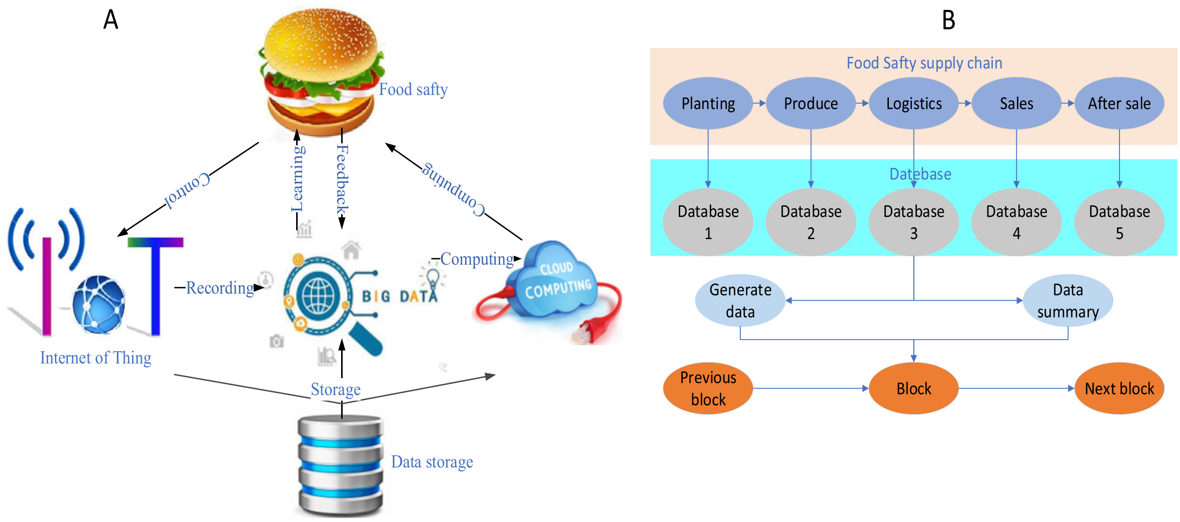

FIGURE 2. The combined advantages of the Internet of Things and big data technology in the food safety traceability system (A) and the food safety data storage model constructed in this research.

operations [8]. Repeat the above steps until the page that is still to be crawled is accessed.

B. ADVANTAGES OF THE COMBINED USE OF IOT AND BIG DATA TECHNOLOGY IN THE FOOD SAFETY TRACEABILITY SYSTEM

In the development process of the food quality and safety traceability system, the integration of the Internet of Things technology and big data technology can complement each other. Firstly, the use of big data technology and smart contracts can better detect and locate malicious nodes; Secondly, the use of asymmetric encryption technology of big data technology can ensure the security of file data and reduce the dependence of the Internet of Things on the central structure. Finally, the centralized platform of the Internet of Things has low compatibility and weak anti-attack ability during the device identity authentication process. Introducing big data technology and storing information such as digital identities in a new block data structure can effectively protect privacy, improve security, and reduce computing overhead. Meanwhile, the increase in the amount of data and the complexity of the structure require cloud servers for memory and storage. In turn, the parallel computing capabilities of cloud computing also promote the efficient and intelligent processing of big data; Big data solves the security problems of information leakage and tampering, and provides basic support and reshaping trust mechanisms for the Internet of Things, big data, cloud computing, etc. Therefore, the advantages of the combined use of IoT and big data technology in the food safety traceability system can be represented by Figure 2A. Based on this, in this article, a food safety data storage model is constructed for the information safety management and traceability of food, as shown in Figure 2B [9], [10]. By verifying the detailed data information on the food supply chain through smart contracts, it is finally stored in a relational database together with the big data location information where the data is located. This not only improves the operating efficiency of big data, but also guarantees the security and credibility of the data.

III. DATA COLLECTION AND PROCESSING OF FOOD SAFETY TRACEABILITY UNDER THE BACKGROUND OF BIG DATA AND THE INTERNET OF THINGS

In the food safety traceability system, multiple data forms such as numbers, images, and videos are involved. In order to extract effective information from it, it is necessary to use various data mining tools and techniques to filter and analyze large amounts of data according to specific individual needs, so as to realize the accuracy and personalization of data, and provide users with good data support [11]. There are three types of data exchange systems used in this study:

(1) Python social auth

A social account authentication/registration mechanism that supports multiple development frameworks including Django, Flask, Webpy, etc. It provides authorization and authentication support for more than 50 service providers, such as Google, Twitter, Sina Weibo and other sites, and the configuration is simple.

(2) Django OAuth Toolkit

It can help Django projects implement data and logic OAuth2 functions, and can be perfectly integrated with the Django REST framework.

(3) Celery

It is used to manage asynchronous and distributed message job queues and can be used in production systems to handle millions of tasks. django-celery is the best choice for executing asynchronous tasks or timing tasks in django web development. Its application scenarios include: Asynchronous tasks: When the user triggers an action that takes a long time to complete, it can be given to celery as a task for asynchronous execution, and then returned to the user after execution. This is similar to using Ajax to implement

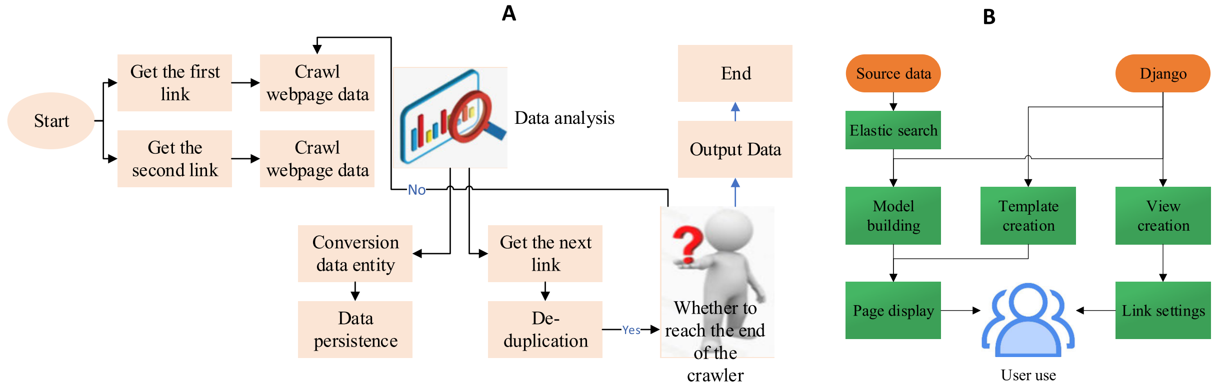

FIGURE 3. The flow chart of the web crawler in this study.

asynchronous loading on the front end. Timed tasks. Celery can help us quickly set different tasks on different machines. Other tasks that can be performed asynchronously. Such as sending SMS, email, push message, cleaning/setting cache, etc.

Therefore, this part relies on big data technology to research an information search engine for food safety traceability. Through the design and development of a web crawler based on the scrapy framework of Python, it crawls the food-related information publicly released on the Internet, classifies and archives it, and provides data support for the food health search engine.

A. DATABASE DESIGN

The database design of this research mainly involves historical information database, real-time monitoring database and web crawling database. The historical database is mainly used for historical data query and display, and it also provides data support for subsequent data analysis. Take the information data in the rice planting process as an example, the detailed design situation is shown in Table 1.

TABLE 1. Design of query table for information data in the process of rice planting.

Value	Type	Description	Empty or not
Id	Int	Home	No
tem	float	Air temperature data	Yes
hum	float	Air humidity data	Yes
tim	date	Time	Yes

The web crawling database is used to store various rice data information crawled from the Internet, mainly including rice commodity information, rice edible information, and rice product information. The various information stored in the early stage provides data protection for subsequent crawlers to crawl the website for classification. This research uses Scrapy for data crawling. Scrapy is an open sources web crawler framework with very practical designs such as automatic deduplication and automatic suspension of access [12]. These designs make the developed web crawler more scalable and robust. The specific web crawler flowchart is shown in Figure 3A.

B. DATA PROCESSING

After obtaining a large amount of food-related data, this research built a small search engine for food. It takes Python's open sources website framework Django as the main body, and uses elastic search technology for data storage. It has the characteristics of clear classification, low article repetition rate, strong pertinence, and no advertisements [13]. It can provide users with accurate and fast data acquisition channels. Elastic search is a distributed database that allows multiple servers to operate at the same time, and each server can run multiple Elastic search instances. The structure of a small search engine website is shown in Figure 3B. The first is the construction of the Model layer. According to the format of data stored in elastic search, three Model classes inherited from the Doc Type class in *elastic search_ dsl* are established, namely commodity Model class, edible Model class and product Model class. Corresponding fields are established according to the specific requirements of different types. The second is the construction of the View layer. In this research, View is mainly responsible for the provision of search suggestions and the keyword search after users click the search and return to the result page. Using the *Request. GET* method to get the keyword entered by the user and the category of the keyword. After a series of formatting, the keywords are sent to elastic search according to different categories, and the returned json string is obtained, and the *json string* is parsed and sorted, and returned to the original page for display. Finally, the construction of the Template layer [14]. This research only developed a small search engine, so the main page only has a search page and a result display page.

C. DATA ANALYSIS PROCESS

Machine learning (ML for short) is a branch of artificial intelligence, which aims to feed various new rules and action reference information to the system according to established steps. This information can be automatically learned by the system to continuously accumulate experience and achieve ''self-improvement''. Artificial intelligence (AI) refers to the ability of machines to continuously learn and apply flexibly according to various scenarios in real life and real-time data.

Its goal is to independently perform certain specific and interrelated tasks by imitating human behavior. In order to achieve the desired purpose, AI can work collaboratively with a variety of program integration, verification mechanisms, and pattern recognition methods. As mentioned earlier, after a certain amount of data has been collected, this research designed an algorithm for the classification of various data of rice. Taking web crawling rice-related databases as an example, the specific algorithm is as follows:

(1) Obtaining the word segmentation classification result table, a total of three, namely the product word segmentation result table H1, the eating method word segmentation table H2, and the product information word segmentation table H3.

(2) Comparing the three words segmentation tables to find the word segmentation data contained in the three words segmentation tables. These data were removed from the three words segmentation tables, and three relatively independent word segmentation tables H1a, H2a, and H3a were obtained.

(3) Obtain the word segmentation result H4 of the rice to be classified. H4 contains $n1$ word segmentation data.

(4) Setting: any value in H4 is exactly the same as any value in table H1a, H2a, H3a, then table H4 has a similar value with H1a, H2a or H3a. According to the following formula, calculate the values of $K1$, $K2$, and $K3$ respectively, see the follow equation as details.

$$K_1 = \frac{\text{Similar values between } \mathrm{H_4} \text{ and } \mathrm{H_{1a}}\ (\mathrm{N_1})}{n_1} \times 100\% \tag{1}$$

$$K_2 = \frac{\text{Similar values between } \mathrm{H_4} \text{ and } \mathrm{H_{2a}}\ (\mathrm{N_2})}{n_1} \times 100\% \tag{2}$$

$$K_2 = \frac{\text{Similar values between } \mathrm{H_4} \text{ and } \mathrm{H_{2a}}\ (\mathrm{N_2})}{n_1} \times 100\% \tag{3}$$

(5) Compare the three values of $K1$, $K2$, and $K3$. The classification table to which the maximum value belongs is the classification to which the result of the rice word segmentation to be classified should belong. If the maximum value contains two, the word segmentation result is added to the classification table to which the two maximum values belong at the same time. If the three values are all equal, the data will be temporarily discarded, and the classification table will be continuously improved before processing.

(6) Output the classification information, and then add this word segmentation result to the corresponding classification table. Enriching the data in the classification table and continue to improve it to provide data support for the next classification [15].

D. ENCRYPTION DESIGN OF TRACEABILITY CODE

In this research, the traceability code encryption is divided into three parts. Firstly, the clear code is generated, and then the clear code is encrypted by the 128-bit Rijndael algorithm, and finally the tail check code is obtained according to the encrypted part, which is combined into an 18-bit traceability code. The body code requires 17 digits, which must be variable and related to the product information. Therefore, the clear code part before encryption is combined with the commodity code, and the global trade item code and batch code are combined to become the clear code to be encrypted. Among them, the Rijndael algorithm is a block algorithm, and its encryption process is a set of reversible operations including Sub Bytes, Shift Rows, Mix Columns, and AddRoundKey. The principle is as follows:

$$\begin{bmatrix} 02 & 03 & 02 & 01 \\ 01 & 02 & 03 & 02 \\ 03 & 01 & 01 & 03 \end{bmatrix} \begin{bmatrix} F_{0.0} & F_{0.1} & F_{0.2} & F_{0.3} \\ F_{1.0} & F_{1.1} & F_{1.2} & F_{1.3} \\ F_{2.0} & F_{2.1} & F_{2.2} & F_{2.3} \end{bmatrix} = \begin{bmatrix} F'_{0.0} & F'_{0.1} & F'_{0.2} & F'_{0.3} \\ F'_{1.0} & F'_{1.1} & F'_{1.2} & F'_{1.3} \\ F'_{2.0} & F'_{2.1} & F'_{2.2} & F'_{2.3} \end{bmatrix} \tag{4}$$

$$F'_{0.n} = (2 \times F_{0.n}) \oplus (3 \times F_{0.n}) \oplus (2 \times F_{2.n}) \oplus F_{3.n} \tag{5}$$

$$F'_{1.n} = (2 \times F_{1.n}) \oplus (3 \times F_{2.n}) \oplus (2 \times F_{3.n}) \oplus F_{0.n} \tag{6}$$

$$F'_{2.n} = F_{1.n} \oplus (3 \times F_{3.n}) \oplus F_{0.n} \tag{7}$$

IV. CONSTRUCTION OF FOOD SAFETY TRACEABILITY SYSTEM

Building a food safety traceability system to realize process perception, source traceability, and risk early warning. This is of great significance for improving the management level of China's food quality and safety, preventing food safety accidents, maintaining the balance of supply and demand, and promoting people's health.

A. FOOD SAFETY TRACEABILITY SYSTEM MODEL IN THE CONTEXT OF THE INTERNET OF THINGS AND BIG DATA

The food safety traceability system is a safety assurance system that uses information technologies such as article coding and radio frequency identification to manage relevant information in the food supply chain. Based on the main structure of the Internet of Things and the data integration and sharing function of big data, the food safety traceability system model under the background of the Internet of Things and big data constructed in this study is shown in Figure 4. The whole is divided into support (hardware) layer, network layer, data layer, display layer, and user layer.

Among them, the support layer (hardware layer) provides software and hardware support for the system, and uses RFID readers and other equipment to monitor and track the whole process of rice production and circulation in real time to collect and encode data. This requires software and hardware devices such as servers, storage devices, network devices, operating systems, and databases. The data layer receives a large amount of basic data through the server, analyzes, organizes and analyzes and finally stores it in the database. And supplemented by a small amount of manual data entry to provide complete data support for the entire traceability system. The network layer aggregates the data carried by each node to the Zigbee gateway through the Zigbee node

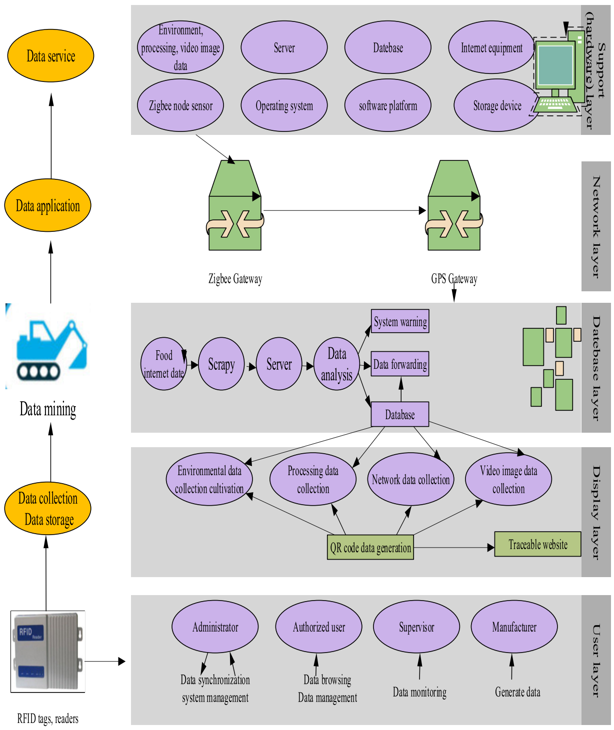

FIGURE 4. Food safety traceability system model in the context of the internet of things and big data.

self-organizing network, and then the Zigbee gateway sends the aggregated data to the GPRS gateway. The GPRS gateway converts the data into a byte array format and sends it to the server via the network [16]. The system layer implements various functions of the food safety traceability system, and the thematic data and business data used by the system come from the data layer. The user layer is the users who use the system and perform corresponding operations according to different permissions. The structure design provides a stable and safe query terminal for consumers who finally purchase the product. Using the unique identification code on the food packaging bag on the website to find important information about food planting, production, and transportation. Using B/S server to build a traceability platform, so that users can query through PC browser client, tablet/mobile client, provide companies with information to guide production, and provide consumers and regulatory authorities with food ingredients, production, processing and circulation processes information.

B. PLATFORM ARCHITECTURE OF FOOD SAFETY TRACEABILITY SYSTEM

This article integrates practical research and industry researchers' data, combined with the above traceable links, to build a platform that can improve the quality of food production, provide users with data, and accept the supervision of the public. The food safety traceability system taking rice as an example is composed of various data, sensors, barcode tags, RFID tags, information management systems and other elements, including user information management, planting information management, processing information management, logistics and distribution information management, sales information management, supervision management, consumer inquiries and problem product management. Among them, user management establishes various operating users for the system and manages users. In the planting information management module, planting administrators and supervisory department administrators can use this module to query, add, modify, and delete key information of the entire rice planting stage. In the processing information management module, processing administrators and supervisory department administrators can use this module to realize the functions of querying, adding, modifying, and deleting key information in the rice processing stage. In the logistics distribution information management module, the supervisory department or logistics enterprise administrator can use this module to realize the functions of query, addition, modification, and deletion of logistics distribution information. In the sales information management module, the supervisory department or administrator can use this module to realize the functions of query, addition, modification, and deletion of processing information. In the supervision management module, consumers can use this module to complain about problem products, and the supervision department can realize functions such as viewing complaint information. In the consumer query module, consumers can query important information about rice planting, production, and transportation by using the unique identification code on the rice packaging bag. In the problematic product management module, the supervisory department or the administrator of the inspection department can implement product inspection through this module. If the product is unqualified, a problematic product record will be generated. In the production and processing system, data can be collected through various IoT sensing devices to ensure the integrity, authenticity and reliability of the data, and set up abnormal value warnings in the system to provide food safety warnings [17]. The specific platform architecture is shown in Figure 5.

C. FOOD TRACEABILITY PROCESS

As mentioned earlier, the management units of the food safety traceability system constructed in this study use bar code and RFID technology to obtain and record basic data, and upload them to the enterprise management information system and big data center through the communication network. In the planting process, after the system collects the relevant data of agricultural planting, the relevant data is encrypted and uploaded to the cloud platform. In retail stores, consumers can obtain relevant information recorded by the food from the grower to the manufacturer and then to the distribution nodes of the retail store by querying barcodes or RFID tags [18]. This realizes that agricultural products can be traced directly to specific producers, and to the relevant information of specific production plots and planting processes. The data transmitted between the logistics link, warehousing link, sales link and the traceability cloud platform is equivalent to the

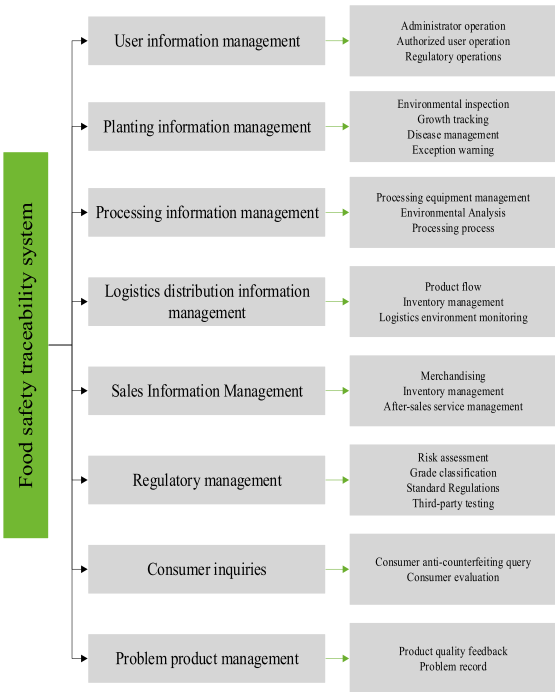

FIGURE 5. Platform architecture of food safety traceability system.

data block of the blockchain. The data transmitted in different links together constitute a complete traceability information, which ensures the completeness of the information in the whole process of traceability and the authenticity and reliability of the traceability information. At the same time, food supervision organizations such as the Food Supervision Bureau, Industry and Commerce, Anti-Counterfeiting Office, Anti-Counterfeiting Office and other departments randomly check whether relevant data is complete or tampered through special terminals. The specific process is shown in Figure 6.

D. SYSTEM NETWORK ARCHITECTURE DESIGN

Since all operations for big data and the Internet of Things are presented in the form of a transaction record, each data record has a unique *tx Hash* address to constrain. By linking the two-dimensional code information of the product with these tx Hash, all traceability information for a product is connected in series and cannot be changed [19]. In order to facilitate the query, we traverse and monitor the data of the entire big data alliance chain, and cache a copy of the data in Mongo Db. The biggest feature of Mongo is that the query language it supports is very powerful, and its syntax is somewhat similar to an object-oriented query language. It can almost achieve most of the functions similar to single-table queries in relational databases, and it also supports indexing of data. This can effectively solve the problems of concurrency and query efficiency, and provide query services for more consumers. Its concrete design is shown as in Figure 7.

E. DATA EXCHANGE SYSTEM DESIGN

The data exchange system establishes a set of bridges between the internal and external networks through

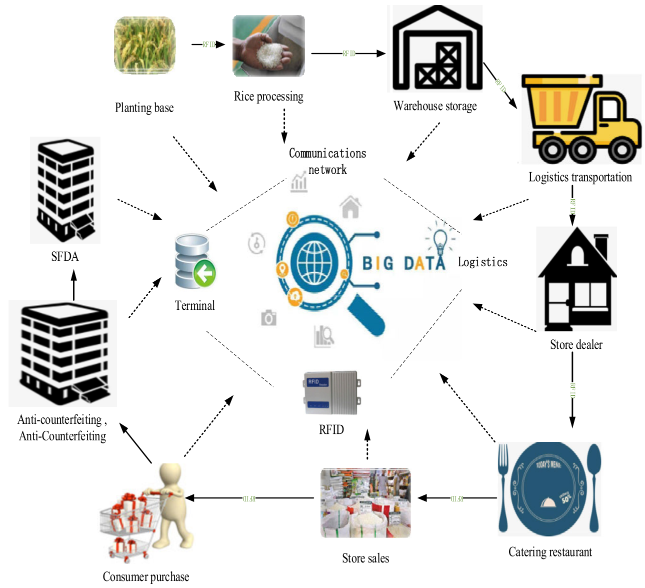

FIGURE 6. Food traceability process of food safety traceability system.

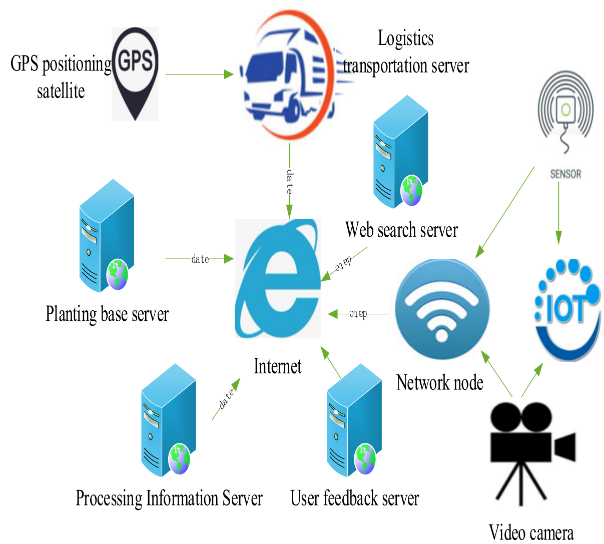

FIGURE 7. System network architecture.

standardized interfaces and general data exchange protocols. It provides convenient, safe and efficient data exchange methods for government agencies and enterprises. The data exchange system in this design provides a Web Service interface for systems that need information exchange, and encapsulates XML messages through a standard SOAP protocol for data exchange. The data exchange system provides a two-way queue technology to realize a symmetrical data interaction mode, so that all multiple systems in the internal and external networks based on the system can achieve mutual data exchange; Because the system has a unified data standard, by using a two-way XML communication standard, it has fully achieved cross-system and cross-application seamless data exchange [20]; At the same time, the system has a variety of interaction methods. In order to adapt to different needs and environments, a variety of data interaction methods are provided internally;

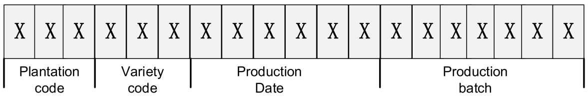

FIGURE 8. **Schematic diagram of the two-dimensional code structure.**

F. INFORMATION INPUT OF FOOD SAFETY TRACEABILITY MANAGEMENT SYSTEM

As a platform for carrying product information, the database needs technical equipment to support the entry of information. In the system, the QR code is the carrier of product traceability information. The QR code carries information about the entire process of the product supply chain. All traceability information can be obtained by scanning the QR code, and further details of the product can be viewed according to the traceability code in the QR code. According to the production information of rice, a two-dimensional code uniquely corresponding to each product is generated, and the realization of functions such as food traceability and information inquiry and tracking requires a unique identification. Consumers or corporate staff can track and query traceability information in the traceability system according to the QR code on the product packaging. The two-dimensional code of the product is carried out in the Andriod operating system, developed through the Eclipse IDE development environment, using Java applications, and finally using Swetake QR Code. The jar function library is designed for the QR code. The QR code generation process is as follows: (1) Enter the encoding information of the QR code into the system with character strings in accordance with the encoding rules; (2) Convert the string in the Swetake QRCode.jar function library to obtain a two-dimensional array that can generate image files; (3) Display the two-dimensional code graphics on the Surface View canvas; At the same time, in this study, the two-dimensional traceability code of the product is composed of 18 Arabic numerals: plantation code (3 digits) + variety code ((3 digits) + production date (6 digits) ten production batches (6 digits),see Figure 8 for detail.

V. IMPLEMENTATION AND TESTING OF FOOD SAFETY TRACEABILITY SYSTEM

The software system runs in all links of the supply chain. Its function is to record the current production and circulation situation, read and write the identification information of each link, send and receive supply chain related data to the database and big data network, and provide functions such as query, traceability, and monitoring. as mentioned earlier, the food safety traceability system sub-systems constructed by this research institute include the big data system for the entire food supply chain, the information security database for the entire food supply chain, and the information security management platform for the entire food supply chain. The system adopts the browser/server (B/S) structure, which is composed of database, server and client.

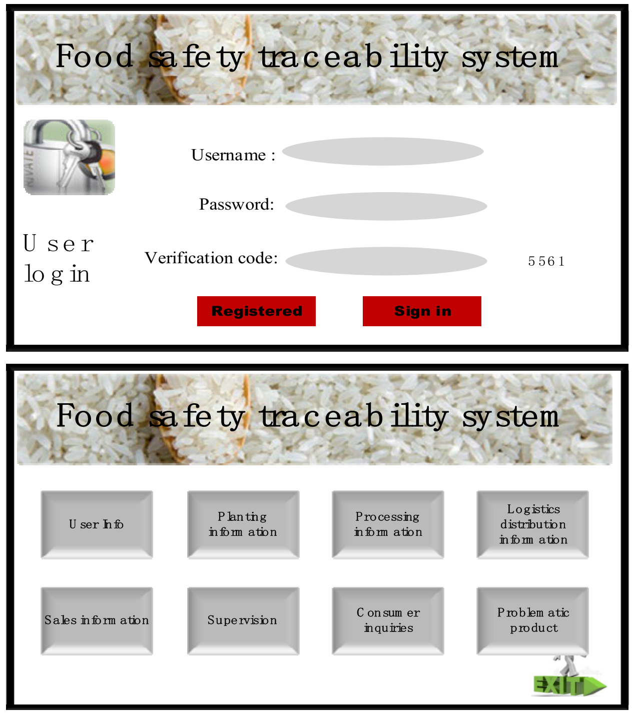

FIGURE 9. **The login interface after the system is running.**

A. SYSTEM OPERATING ENVIRONMENT AND EQUIPMENT SUPPORT

The system development uses Microsoft Visual Studio 2018 and SQL server 2019 to develop the PC center control terminal, and the android version of eclipse to develop the mobile terminal. The equipment involved includes UHF RFID card readers, barcodes, QR code thermal printers, food safety tachometers, IP network cameras, etc. It is required that the corresponding equipment can be connected to the central control system through the USB interface, the serial food safety traceability system port server, and the network center switch [21], [22]. The connection between the wireless radio frequency reading and writing equipment and the computer generally adopts com (RSR232) interface or usb interface. Each function of the system is encapsulated into an interface, and the interfaces are independent of each other. The client obtains the data that the user is interested in by calling the interface and writes it into the display control.

B. REALIZATION OF FOOD SAFETY TRACEABILITY SYSTEM PAGE

Take the user login interface as an example. This page is a verification page for legitimate users. After selecting the identity in the corresponding position on the page, and inputting the user name and password, the encapsulated BLL method is called to compare with the user name and password in the database. If it exists, it is a legitimate user and enter the system, otherwise an error message will pop up. The interface after the system is running is shown in Figure 9.

C. IMPLEMENTATION OF FOOD SAFETY TRACEABILITY SYSTEM CODE

The eight subsystems of user information management, planting information management, processing information management, logistics distribution information management, sales information management, supervision management, consumer inquiry, and problem product management constructed in this research all involve the addition and modification of data information. The operation of processing records [23], [24]. Therefore, taking the operation of adding and modifying processing records of data information in the system as an example, the main code to realize this operation is as follows:

```
{
If (IsIconic ())
{
C Paint DC do (this);//device context for painting
Send Message (WPRRRM) dc.GetSafeHdc();
//Center icon in client rectangle
int cxIcon – Get System Message(SM_CXICON);
int cyIcon=Get System Metrics (SM_CYICDN);
CRect rest;
Get Client Rect(&erect);
Int x=(rect.Width( )-cxIcon+1)/2;
Int y=(rect.Heigth( )-cxIcon+1)/2;
//Draw the icon dc.DrawIcon[x, y, m_ hIcon);
} else
{
CDialog::OnPaint();
}
}
```

D. REALIZATION OF DATA QUERY FUNCTION

Taking rice planting traceability as an example, this system provides two historical data query methods. The first is to query the real-time data of the year, according to the time period selected by the user, to query the real-time data. The graph and table drawn with the Chart control are displayed in two forms, which can provide users with more efficient services [25]. The second is the query of historical data over the years, according to the user's selected years, to query the brief information of a certain period of time, such as air temperature, air humidity, and light conditions. The real-time data stores the current year's air temperature and humidity, soil temperature and humidity, and light conditions. Select the time you need to query, click the OK button, and get the corresponding data information.

E. MOBILE TERMINAL QUERY FOR FOOD SAFETY TRACEABILITY (IMPLEMENTATION OF INFORMATION ACCESS PAGE)

The database carrying product information is presented in the form of a website platform to form a scientific, complete and convenient safety traceability system [26]–[28]. Design a dynamic website and implement a systematic query platform

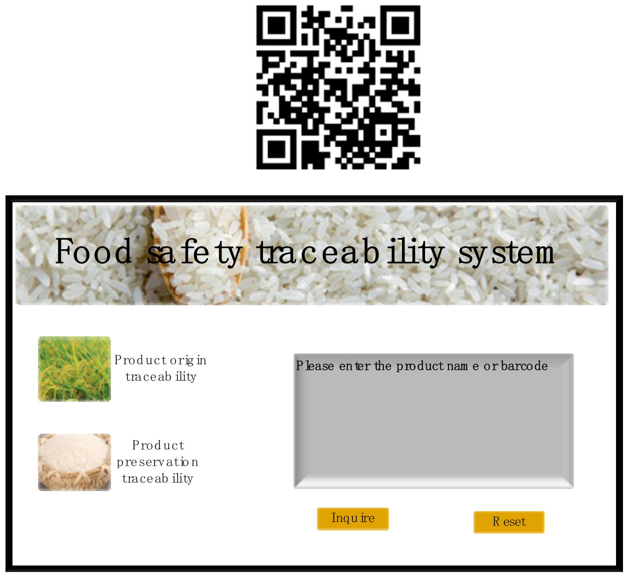

FIGURE 10. Schematic diagram of the QR code on the rice product packaging and the mobile terminal information query page.

to enable enterprise staff to perform operations such as information entry, management, and query, and enable consumers to query product information or provide opinions and suggestions to the enterprise [29]–[33]. In this study, taking rice as an example, the raw materials, auxiliary materials, operating procedures, processing management personnel, food sampling quality inspection information, real-time monitoring values of key control points in HACCP and other information during rice processing must be uploaded to the database. Then integrate the information in the database, generate a two-dimensional code through the coding rules constructed by this system, and print it on the outer packaging of the product one-to-one; Relevant information about transportation, storage, entry and exit, handling personnel, and sales should also be uploaded to the database for storage. After consumers purchase the product, they can scan the QR code on the food package through the camera of their mobile phone to learn about the production information of the product. The two-dimensional code and mobile terminal information query page on the rice product packaging are shown in Figure 10.

F. TEST CASES FOR EACH SUBSYSTEM

This part mainly verifies the functions of each functional module of the system and the stability of the system, the test requirements are shown in Table 2. At the same time, the test of this system mainly includes the verification test of the basic functions of the system, the registration test and the stability test. Table 3 lists some test cases of the system.

G. REALIZATION OF REAL-TIME MONITORING

During the transportation and storage of raw food, changes in various environmental factors have an extremely important impact on the quality of food. Therefore, whether the control system can be used to more accurately and quickly deal with environmental mutations in the pig house is extremely

TABLE 2. System test requirements.

Test phase	Testing method	Testing requirements
Functional verification of each module	Check the function of the operation button (add, delete, modify, cancel)	Check whether the operation function of each button is accurate.
	Check the purpose and description of the operation buttons	Whether the button names or description texts of the same purpose in different modules are the same
	Check required field settings	Whether the system can give corresponding restrictions
	Data query correctness	Meet the query requirements
	Interface check	Check whether the overall style of the interface is consistent and the layout of tables, user prompts, menus and dialog boxes, etc.
	Abnormal input check	Verify that the system gives correct judgments for abnormal data in the second stage of system stability
System stability	Count the error rate under normal operation	Under normal operation, no errors should occur
	Count the error rate generated under any operation. Record common error messages	Under any operation, the fewer errors, the better

TABLE 3. System test case analysis.

Subsystem	Test items	User action	System response
Login system	Function test	Enter the login page correctly	Whether the landing page is displayed correctly
		User password correct test	Navigate correctly to enter the functional interface corresponding to the user
		User password is not completely correct test	Prompt the user that the password is wrong, redirect to the login page, and remind to re-enter
		When visiting other pages, whether the login information is correctly detected	When you visit other pages when you are not logged in, you can correctly redirect to the landing page
Logistics distribution information management	Function test	Able to correctly edit, delete, view agricultural information and accurately query functional tests;	When the user clicks on the distribution information management, all agricultural information will be displayed;
Processing information management	Function check	Can correctly edit, delete, view the collected information, and check the accurate query function	When the user clicks on the processing information management, all collected information will be displayed; When you click edit, delete, or view, go to the corresponding page

important. In order to improve the environmental monitoring of rice transportation and storage, the food safety traceability system constructed by this research institute is equipped with temperature and humidity sensors, which can realize the control of environmental factors during the transportation and storage of food. Detecting and tracing the changes of temperature and humidity in the environment during the transportation and storage of rice are of great significance to the protection of food quality and people's health. Take the change of environmental temperature and humidity during the transportation and storage of rice as an example, briefly describe the actual and theoretical values of environmental temperature and humidity monitoring in this system. The temperature and humidity adjustment and monitoring and the simulation value, test value and relative error of each test node are shown in Table 4 and Table 5.

From the results Table 4 and Table 5, it can be seen that the monitoring subsystem in this food safety traceability system can help users reduce labor costs during rice transportation and storage. In the long run, the benefits of users are improved, and the quality of rice and people's health are also guaranteed.

In order to improve the environmental monitoring of rice transportation and storage, the food safety traceability system

TABLE 3. *(Continued.)* System test case analysis.

Consumer inquiries	Function check	The user enters a traceability code that does not exist or is wrong, and the check reminder	Prompt that the traceability code is incorrect, and give the correct traceability code length and format.
		function checks and outputs the specific information of the dish	The user enters the correct traceability code

TABLE 4. Temperature control results.

Number	Default value(℃)	Actual value(℃)	Relative error（℃）
1	25.0	25.0	0
2	26.4	26.2	-0.2
3	24.7	24.8	0.1
4	25.1	25.0	-0.1
5	24.9	25.0	0.1
6	25.3	25.4	0.1

TABLE 5. Humidity control results.

Number	Default value(%)	Actual value(%)	Relative error（%）
1	65.0	65.4	0.4
2	66.4	66.1	0.3
3	64.8	65.2	-0.4
4	64.5	65.0	-0.5
5	65.5	65.1	0.4
6	66.0	65.4	-0.6

constructed by this research institute is equipped with temperature and humidity sensors, which can realize the control of environmental factors during the transportation and storage of food. Detecting and tracing the changes of temperature and humidity in the environment during the transportation and storage of rice are of great significance to the protection of food quality and people's health. Take the change of environmental temperature and humidity during the transportation and storage of rice as an example, briefly describe the actual and theoretical values of environmental temperature and humidity monitoring in this system. The temperature and humidity adjustment and monitoring and the simulation value, test value and relative error of each test node are within the error range.

VI. CONCLUSION

In the context of epidemic prevention and control, strengthening food safety data analysis based on the application of food safety traceability technology can effectively improve the effect of food safety management, which is conducive to the development of epidemic prevention and control, and has practical value for the solution of future food safety issues in China as a whole. So as to better protect people's life, health and safety. The use of Internet of Things technology to regulate food safety can effectively curb the emergence of major food safety incidents. Moreover, the problem can be diagnosed more real-time and accurately, and the source of the hazard can be quickly identified, so that the quality of the food is more guaranteed. This will have a huge impact on the food supply chain. At the same time, under the intelligent monitoring of big data, it is difficult for companies in the food supply chain to tamper with the data, ensuring the authenticity of the data. Combining big data, the Internet of Things, the Internet and the food traceability system will truly achieve openness, transparency, and completeness of information, and strictly control the various steps of the food traceability system, so that the value of the food traceability system can be truly realized. This research uses IoT technology, wireless sensor technology, RFID technology, crawler technology, database technology and other related technologies to design and implement a set of food traceability system using rice as an example. It has initially completed the traceability requirements for the entire process of food products, and also provided network data information for food-related industries. The implementation of traceability is not only a practical need to ensure food safety, but also the main means of current and future food safety measures. Through combing and researching the existing food safety traceability system, drawing on advanced domestic and foreign experience and achievements, strategically, systematically and structurally, establish a unified and standardized food safety traceability standard system, and establish a food safety traceability system for the government and enterprises Provide standardized technical guidance, it also provides standard support for the establishment of third-party certification, thereby improving the level of food safety traceability and people's health.

REFERENCES

[1] J. Wang, H. Yue, and Z. Zhou, "An improved traceability system for food quality assurance and evaluation based on fuzzy classification and neural network," *Food Control*, vol. 79, pp. 363–370, Sep. 2017.
[2] Q. Lin, H. Wang, X. Pei, and J. Wang, "Food safety traceability system based on blockchain and EPCIS," *IEEE Access*, vol. 7, pp. 20698–20707, 2019.
[3] G Alfian, M. Syafrudin, U. Farooq, M. R. Ma'arif, M. A. Syaekhoni, N. L. Fitriyani, J. Lee, and J. Rhee, "Improving efficiency of RFID-based traceability system for perishable food by utilizing IoT sensors and machine learning model," *Food Control*, vol. 110, Apr. 2020, Art. no. 107016.
[4] F. Liu, Y. Wang, Y. Jia, S. Hu, L. Tu, and C. Tang, "The egg traceability system based on the video capture and wireless networking technology," *Int. J. Sensor Netw.*, vol. 17, no. 4, pp. 211–216, Apr. 2015.
[5] X. Xiao, Z. Fu, L. Qi, T. Mira, and X. Zhang, "Development and evaluation of an intelligent traceability system for frozen tilapia fillet processing," *J. Sci. Food Agricult.*, vol. 95, no. 13, pp. 2693–2703, Oct. 2015.
[6] M. M. Aung and Y. S. Chang, "Traceability in a food supply chain: Safety and quality perspectives," *Food Control*, vol. 39, pp. 172–184, May 2014.

[7] E. Abad, F. Palacio, M. Nuin, A. G. D. Zárate, A. Juarros, J. M. Gómez, and S. Marco, "RFID smart tag for traceability and cold chain monitoring of foods: Demonstration in an intercontinental fresh fish logistic chain," *J. Food Eng.*, vol. 93, no. 4, pp. 394–399, Aug. 2009.

[8] T. Bosona and G. Gebresenbet, "Food traceability as an integral part of logistics management in food and agricultural supply chain," *Food Control*, vol. 33, no. 1, pp. 32–48, Sep. 2013.

[9] F. Tian, "A supply chain traceability system for food safety based on HACCP, blockchain & Internet of Things," in *Proc. Int. Conf. Service Syst. Service Manage.*, Jun. 2017, pp. 1–6.

[10] J. F. Galvez, J. C. Mejuto, and J. Simal-Gandara, "Future challenges on the use of blockchain for food traceability analysis," *TrAC Trends Anal. Chem.*, vol. 107, pp. 222–232, Oct. 2018.

[11] G. P. Danezis, A. S. Tsagkaris, F. Camin, V. Brusic, and C. A. Georgiou, "Food authentication: Techniques, trends & emerging approaches," *TrAC Trends Anal. Chem.*, vol. 85, pp. 123–132, Dec. 2016.

[12] M. Thibaud, H. Chi, W. Zhou, and S. Piramuthu, "Internet of Things (IoT) in high-risk environment, health and safety (EHS) industries: A comprehensive review," *Decis. Support Syst.*, vol. 108, pp. 79–95, Apr. 2018.

[13] K. Salah, N. Nizamuddin, R. Jayaraman, and M. Omar, "Blockchain-based soybean traceability in agricultural supply chain," *IEEE Access*, vol. 7, pp. 73295–73305, Aug. 2019.

[14] M. Lv, Y. Liu, J. Geng, X. Kou, Z. Xin, and D. Yang, "Engineering nanomaterials-based biosensors for food safety detection," *Biosensors Bioelectron.*, vol. 106, pp. 122–128, May 2018.

[15] K. Behnke and M. Janssen, "Boundary conditions for traceability in food supply chains using blockchain technology," *Int. J. Inf. Manage.*, vol. 52, Jun. 2020, Art. no. 101969.

[16] R.-Y. Chen, "An intelligent value stream-based approach to collaboration of food traceability cyber physical system by fog computing," *Food Control*, vol. 71, pp. 124–136, Jan. 2017.

[17] H. Huang, L. Liu, and M. Ngadi, "Recent developments in hyperspectral imaging for assessment of food quality and safety," *Sensors*, vol. 14, no. 4, pp. 7248–7276, Apr. 2014.

[18] C. M. Galanakis, "The food systems in the era of the coronavirus (COVID-19) pandemic crisis," *Foods*, vol. 9, no. 4, p. 523, Apr. 2020.

[19] X. Zhang, S. Lv, M. Xu, and W. Mu, "Applying evolutionary prototyping model for eliciting system requirement of meat traceability at agribusiness level," *Food Control*, vol. 21, no. 11, pp. 1556–1562, Nov. 2010.

[20] Y. Dong, Z. Fu, S. Stankovski, S. Wang, and X. Li, "Nutritional quality and safety traceability system for China's leafy vegetable supply chain based on fault tree analysis and QR code," *IEEE Access*, vol. 8, pp. 161261–161275, Feb. 2020.

[21] W. Liu, W. Cheng, and J. Zhang, "Study on the traceability system establishment of safety-objective-oriented food logistics supply chain," *Advance J. Food Sci. Technol.*, vol. 5, no. 4, pp. 492–499, Apr. 2013.

[22] R.-Y. Chen, "Autonomous tracing system for backward design in food supply chain," *Food Control*, vol. 51, pp. 70–84, May 2015.

[23] J. An-Qi, C. Xiu-Lian, L. I. Ming-Fu, and J. Zong-Yue, "Application of traditional Chinese medicine (TCM) traceability system based on TCM quality characteristics and HACCP system," *China J. Chin. Materia Medica*, vol. 45, no. 21, pp. 5304–5308, Aug. 2020.

[24] M. Deng and P. Feng, "A food traceability system based on blockchain and radio frequency identification technologies," *J. Comput. Commun.*, vol. 8, no. 9, pp. 17–27, 2020.

[25] G. Zhao, X. Sun, and X. Y. Wang, "Research on the vegetable quality safety traceability system based on Internet of Things and biosensor," *J. Food Saf. Qual.*, vol. 6, no. 3, pp. 747–755, Dec. 2015.

[26] M. Castro-Puyana, R. Pérez-Míguez, L. Montero, and M. Herrero, "Application of mass spectrometry-based metabolomics approaches for food safety, quality and traceability," *TrAC Trends Anal. Chem.*, vol. 93, pp. 102–118, Aug. 2017.

[27] T. Pizzuti, G. Mirabelli, G. Grasso, and G. Paldino, "MESCO (MEat supply chain Ontology): An ontology for supporting traceability in the meat supply chain," *Food Control*, vol. 72, pp. 123–133, Feb. 2017.

[28] M. C. Chen, S. Q. Lu, and Q. L. Liu, "Uniform regularity for a Keller–Segel–Navier–Stokes system," *Appl. Math. Lett.*, vol. 107, Sep. 2020, Art. no. 106476.

[29] W. Wei, M. Guizani, S. H. Ahmed, and C. Zhu, "Guest editorial: Special section on integration of big data and artificial intelligence for Internet of Things," *IEEE Trans. Ind. Informat.*, vol. 16, no. 4, pp. 2562–2565, Apr. 2020.

[30] J. Han, N. Lin, J. Ruan, X. Wang, W. Wei, and H. Lu, "A model for joint planning of production and distribution of fresh produce in agricultural Internet of Things," *IEEE Internet Things J.*, early access, Nov. 16, 2020, doi: 10.1109/JIOT.2020.3037729.

[31] W. Wang, N. Kumar, J. Chen, Z. Gong, X. Kong, W. Wei, and H. Gao, "Realizing the potential of Internet of Things for smart tourism with 5G and AI," *IEEE Netw.*, vol. 34, no. 6, pp. 295–301, Nov./Dec. 2020.

[32] S. Qi, Y. Lu, W. Wei, and X. Chen, "Efficient data access control with fine-grained data protection in cloud-assisted IIoT," *IEEE Internet Things J.*, vol. 8, no. 4, pp. 2886–2899, Feb. 2021, doi: 10.1109/JIOT.2020.3020979.

[33] S.-W. Chen, D. L. Chiang, C.-H. Liu, T.-S. Chen, F. Lai, H. Wang, and W. Wei, "Confidentiality protection of digital health records in cloud computing," *J. Med. Syst.*, vol. 40, no. 5, p. 124, May 2016.

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