ISSN 2616-7433 Vol. 6, Issue 11: 74-79, DOI: 10.25236/FSST.2024.061113

An IoT-Driven Architectural Framework for a Food Quality Monitoring and Safety Management System

Su Weiming, Nor Adnan Yahaya

University Malaysia of Computer Science & Engineering, Putrajaya, Malaysia, 62000

Abstract: *This study explores the application of Internet of Things (IoT) technology in food quality monitoring and safety management systems, analyzing its impact across various stages of the food supply chain and assessing the feasibility of establishing an efficient and transparent food safety management system. It discusses the challenges faced by food safety management, especially as the complexity of the supply chain continues to increase, making traditional monitoring methods insufficient to meet demands. The study explores the applications of IoT in the food industry, including real-time monitoring in cold chain logistics, production tracking in large enterprises, and smart packaging. Research indicates that IoT technology significantly enhances transparency and monitoring efficiency across the supply chain. However, the application of IoT still needs to overcome challenges related to high costs, data privacy and security, and a lack of standardization, while policy support and technological advancements remain crucial areas for further development.*

Keywords: *Food Safety Management, Internet of Things, Food Supply Chain,Real-Time Monitoring, Food Traceability, Blockchain, Data Transparency, Data Privacy and Security*

1. Introduction

1.1 Context and Background

In recent years, frequent food safety incidents have not only endangered public health but also seriously undermined societal trust and stability. As the global supply chain continues to expand, food faces potential risks at every stage of production, processing, transportation, and sales. For example, clenbuterol incident (2011), the "poisonous bean sprouts" event (2011),and the "red pitaya" event (2017) all exposed the shortcomings of the traditional food safety management system[1]. These incidents highlight the deficiencies of the current food safety management mechanisms in haFigure：schematic diagram of food safety data intelligence supervises big data centersndling the complexities of an increasingly globalized supply chain.

1.2 Importance of IoT in Food Safety

The rapid development of Internet of Things (IoT) technology has paved a new way to enhance the transparency and efficiency of food safety management. Through the use of sensors, radio frequency identification (RFID), and other technologies, IoT can collect real-time data during the food production and distribution process, significantly improving the real-time monitoring and accuracy of food quality. Furthermore, the combination of big data analysis, artificial intelligence, IoT, and blockchain technologies helps to identify potential problems earlier and effectively prevent food safety incidents from occurring.

1.3 Research Objectives

The main objectives of this paper are to explore the applications of IoT technology in food quality monitoring and safety management systems, analyze its impact on various stages of the food supply chain, and examine the feasibility of building an efficient and transparent food safety management system. This paper will investigate how IoT can enhance real-time monitoring, improve food quality management, and play a critical role in ensuring food safety.

ISSN 2616-7433 Vol. 6, Issue 11: 74-79, DOI: 10.25236/FSST.2024.061113

1.4 Structure of the Paper

The paper is structured into several key sections. First, it introduces the current challenges in food quality and safety management. Next, it focuses on how IoT technology addresses these challenges by providing real-time monitoring and traceability solutions. Following that, the paper explores the application of IoT in different stages of the food supply chain and its impact on food quality and safety management. Finally, the paper concludes by summarizing the potential value of IoT in food safety management and offering recommendations for future development.

2. An Overview of the IoT technology

2.1 Internet of Things system Architecture

The architecture of the Internet of Things system is usually divided into three parts: perception layer, transmission layer and application layer:

Sensing layer: It is responsible for collecting data through various sensing devices. These devices can be temperature sensors, humidity sensors, position modules, RFID tags, etc., used to monitor the status of food in each link.

Transmission layer: it is responsible for transferring the collected data to the data processing center through the wireless network or the wired network. Common transmission technologies include WiFi, Bluetooth, 4G / 5G, LoRa, and more.

Application layer: Responsible for analyzing and processing the data, generating decision information, and providing it to managers and related personnel. The application layer usually combines blockchain technology, big data management technology, artificial intelligence and other technologies, and blockchain technology for in-depth analysis to realize intelligent food safety management.

2.2 The application status of the Internet of Things technology in the food industry

The Internet of Things technology has been initially applied in every link of the food industry. For example, many cold chain logistics enterprises use temperature sensors and GPS systems to monitor the temperature and location changes of food during transportation to ensure the freshness of food during transportation. Some large food producers have applied RFID technology on their production lines to track the production status of each batch of food in real time. In addition, intelligent packaging technology is also gradually emerging, which can dynamically monitor the shelf life and storage environment of food.[2]

3. Current status and challenges of food quality monitoring and safety management

3.1 Current situation of Food safety management in China

The Chinese government has continued to promote the improvement of laws and regulations in the field of food safety management, especially the revision and implementation of the Food Safety Law. Since its implementation in 2015, the law has strengthened supervision over food production and distribution, defined the responsibility system for food safety[3], and increased penalties for illegal acts. To ensure food safety, China has set up several regulatory agencies, such as the State Administration for Market Regulation, to supervise and manage food safety. At the same time, the local governments have also established a corresponding food safety supervision system. The establishment of these institutions has made food safety regulation more systematic and professional.

In addition, with the application of the Internet of Things, big data and artificial intelligence technologies[4], the transparency and efficiency of food safety management have been significantly improved. Through real-time monitoring and data analysis, regulatory authorities can identify and deal with food safety issues more timely manner. Despite some achievements, Chinas food safety management still faces multiple challenges.

ISSN 2616-7433 Vol. 6, Issue 11: 74-79, DOI: 10.25236/FSST.2024.061113

3.2 Problems existing in the traditional food quality monitoring and management methods

The traditional food quality monitoring methods mainly include: manual sampling and testing, regular samples from the food production line or market for testing. Although this method can ensure certain quality control, there are large area problems of missed detection due to limited sampling and low coverage and timeliness. Laboratory analysis, through chemical analysis, microbial detection and other means, to determine the composition and quality of food. However, this method requires a long detection cycle and cannot achieve real-time monitoring and supervision.[5] Regulatory agencies supervise, and government departments ensure the compliance of food enterprises through irregular inspections, but due to resource restrictions, the frequency and scope of inspections are limited.

3.3 Key Challenges in Food quality monitoring and safety management

The complexity of the food supply chain makes the information transmission between the links inefficient and leads to information asymmetry. In addition, the traditional food quality monitoring system is slow to respond to emergencies, and it is difficult to find and deal with food safety problems in time. At the same time, with the improvement of consumer awareness of food safety, the demand for transparency and traceability is also increasing, and the existing regulatory means have been unable to meet this demand.[6]

4. Design of food quality monitoring and safety management system based on the Internet of Things technology

This paper explores a multi-layered food management system architecture that integrates information collection, business management[7], data processing, and technical support to enhance food production, tracking, early warning, and decision-making functions.See the table below for details:

application layer				
Information collection system	data management system	WMS	Dispatch management system	Auxiliary decision-making system
Business layer				
Food production and early warning	Food information tracking	Food processing traceability	Food business to assist in decision-making	Food information customized push
Data Layer				
Labbel and item database	Communication database	Logistics database	Map business database	Drive the control database
Support layer				
transducer technology	RFDI technology	GIS technology	GPS technology	Wireless communication technology
Basic layer				

Figure 1 Design of food quality monitoring and safety management system based on the Internet of Things technology

ISSN 2616-7433 Vol. 6, Issue 11: 74-79, DOI: 10.25236/FSST.2024.061113

4.1 Perception layer: collection of food quality data

The sensor types included in the perception layer are shown in the“Basic layer”section of Figure 1. The sensing layer of the Internet of Things monitors key parameters in the production, processing, transportation and sales of food through various sensing devices. For example, in cold-chain transport, temperature sensors can accurately monitor the temperature of the transport environment, ensuring that frozen food remains within the appropriate temperature range. In addition, RFID and QR code technologies can record the production date, shelf life and transportation path of each batch of food, realizing the whole process of food traceability.

4.2 Transmission layer: data communication and network architecture

For details of the transport layer, see the "Data Layer" section in Figure 1.The transmission layer transfers the data collected by the sensing layer to the cloud or the local server through the wireless communication technology. Different transmission technologies have different application scenarios. For example, WiFi is suitable for short-distance data transmission inside a factory, while LoRa technology is suitable for long-distance, low-power data transmission requirements. In the food supply chain, the stability and safety of data transmission is particularly important, especially in the cross-border food trade, and the real-time nature of data plays a key role in ensuring food quality.

4.3 Support decision-makers layer: Data processing and decision support

The specific content of the Support decision-makers layer is in the “Business layer”and “Support layer”of Figure 1.At the Support decision-makers layer, the collected data is analyzed through big data technology, so that enterprises can understand the status of each batch of food in real time and predict potential quality problems. For example, abnormal fluctuations in temperature data may mean a cold chain system failure, while microbiological detection data can help predict the shelf life of food. Through the intelligent decision support system, enterprise managers can make timely adjustments to avoid the expansion of quality problems.

4.4 Construction of a food safety management platform

The construction of the food safety management platform belongs to the construction of the application layer. For details, please refer to the“application layer” of Figure 2.

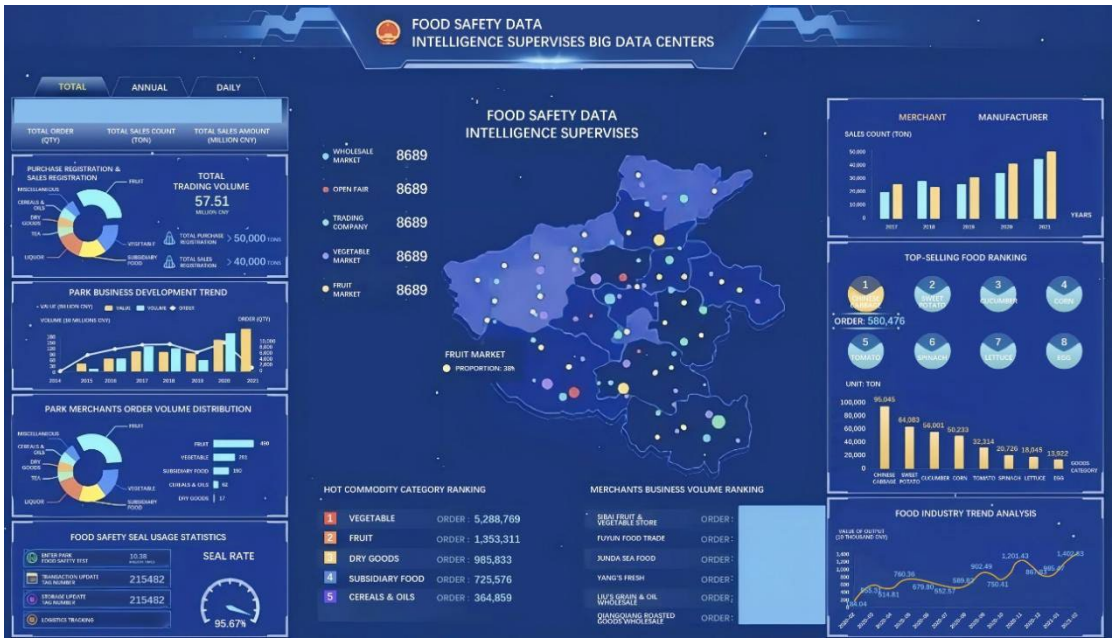

Figure 2 Schematic diagram of food safety data intelligence supervises big data centers

The Internet of Things technology can also be combined with blockchain technology to improve the transparency of food safety management systems. Blockchain, through its imtamable nature, ensures that data at every link in the food supply chain is reliably recorded and traced. The government,

ISSN 2616-7433 Vol. 6, Issue 11: 74-79, DOI: 10.25236/FSST.2024.061113

enterprises and consumers can share data through this platform to improve the efficiency and credibility of food safety supervision.

5. Food safety management system based on the Internet of Things

5.1 Real-time monitoring in the food supply chain

The food quality monitoring system based on the Internet of Things covers the entire supply chain of food from production to consumption. Through real-time monitoring of the food production environment (such as temperature, humidity, light, etc.), the Internet of Things technology can ensure that food meets safety standards in the production process. In the processing and transportation link, the intelligent monitoring system can automatically detect and record the quality state of food, such as temperature, microbial content, etc., to realize the visual management of the whole process.[8]

5.2 Food traceability system design

The combination of the Internet of Things technology and the food traceability system has greatly enhanced the transparency of food. RFID tags and QR code technology can record key information such as the production, processing, storage and transportation of food, and consumers only need to scan the QR code on the package through their mobile phones, then they can query the origin, production date and transportation path of food in real time. Combined with blockchain technology, the security and authenticity of these data are guaranteed.[9]

5.3 Intelligent packaging and quality early warning system

Intelligent packaging technology can monitor the quality of food in real time by embedding sensors in the packaging. For example, when the gas composition in the package changes, the smart package automatically issues a warning that the food may be close to deterioration. Such smart packaging can not only reduce food waste, but also improve consumers trust in food quality.

6. Advantages and challenges of the food safety management system based on the Internet of Things

6.1 Advantages of the Internet of Things technology

The application of the Internet of Things technology in the food industry has the following significant advantages:

Real-time monitoring: The Internet of Things technology realizes the real-time monitoring of the whole process of food from production to consumption, and can timely detect and prevent food quality problems.

Data transparency: Through data sharing and disclosure, the Internet of Things has enhanced the transparency of the food supply chain and enhanced consumers trust in food safety.

Automation management: The Internet of Things technology improves the automation degree of the food safety management process, reduces the dependence on manual intervention, and reduces the incidence of human error.

6.2 Challenges of the application of the Internet of Things technology in the food industry

Although the Internet of Things technology has shown great potential in food safety management, its application also faces some challenges:

Technology cost: The deployment and maintenance costs of the Internet of Things systems are relatively high, especially for small and medium-sized enterprises, where the initial investment pressure is greater.[10]

Data privacy and security: The collection and transmission of large amounts of data in the food supply chain may cause data privacy and security issues. How to ensure the security of data in the transmission process is an important issue.

ISSN 2616-7433 Vol. 6, Issue 11: 74-79, DOI: 10.25236/FSST.2024.061113

Standardization problem: At present, the standards for the application of the Internet of Things in the food industry have not been completely unified, and the lack of consistent specifications has hindered the wide application of the Internet of Things system.

6.3 Solutions and future development trends

To address these challenges, the following steps can be taken in the future:

Cost reduction: Gradually reduce the cost of deploying IoT systems, especially the cost of sensors and communications equipment, through technological advances and scale production.

Improve data security: to ensure data security in the food supply chain through data encryption, identity authentication and other technical means.

Policy promotion: The government should actively promote the standardization of Internet of Things technology in the food industry, and introduce relevant policies to guide enterprises to adopt Internet of Things technology to improve the level of food safety management.

7. Conclusion

Through the research of this paper, it can be seen that the Internet of Things technology has significant advantages in food quality monitoring and safety management. It can not only improve the real-time performance and accuracy of monitoring, but also enhance the transparency and traceability of the food supply chain. The wide application of Internet of Things technology provides new tools and means for food safety management, which can effectively reduce the occurrence of food safety accidents.

References

[1] Wang, Y., Wang, J., & Liu, Y. (2016). Internet of Things for Food Quality Monitoring: A Review. Journal of Food Quality, 2016, 1-12. DOI:10.1155/2016/6395937.
[2] Zhao, Y., & Zhang, Y. (2019). A Framework for Food Safety Management in the Supply Chain Based on the Internet of Things. Sustainability, 11(22), 6345. DOI:10.3390/su11226345.
[3] Fang, J., Wang, H., & Wei, J. (2018). IoT-Based Smart Packaging for Food Safety: A Review. Critical Reviews in Food Science and Nutrition, 58(2), 313-326. DOI:10.1080/10408398.2016.1143736.
[4] Li, B., Chen, L., & Chen, X. (2018). Blockchain Technology for Food Safety: A Systematic Review. Food Control, 86, 198-210. DOI:10.1016/j.foodcont.2017.12.015.
[5] Tseng, M.-L., & Chiu, A. S. F. (2017). A Study on Food Safety Management Systems: The Role of Information Technology. Food Quality and Preference, 61, 110-117. DOI:10.1016/j.foodqual.2017.05.015.
[6] Cao, Y., & Wang, C. (2019). Research on the Food Safety Traceability System Based on IoT and Blockchain Technology. Journal of Food Safety, 39(4), e12658. DOI:10.1111/jfs.12658.
[7] Xie, J., Zhang, Y., & Li, S. (2020). The Role of IoT in Enhancing Food Safety and Quality: A Review. Frontiers in Nutrition, 7, 1-10. DOI:10.3389/fnut.2020.00004.
[8] Bevilacqua, M., & Petruzzelli, A. M. (2018). Challenges and Opportunities for the Adoption of IoT in Food Supply Chains: A Review. Computers in Industry, 97, 141-157. DOI:10.1016/j.compind.2017.10.016.
[9] Shen, L., & Tan, B. (2021). Challenges and Solutions in the Application of IoT Technology in the Food Supply Chain. Journal of Cleaner Production, 278, 123586. DOI:10.1016/j.jclepro.2020.123586.
[10] Zhang, J., Xu, Z., & Yang, S. (2022). Intelligent Packaging Technology and Its Application in Food Safety: A Comprehensive Review. Food Packaging and Shelf Life, 30, 100800. DOI:10.1016/j.fpsl.2021.100800.