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Intelligent Food Quality Monitoring Through Internet of Things, Artificial Intelligence, and Automation: A Review of Emerging Applications

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Abstract - The quality and safety of food are vital issues in contemporary food supply chains, where improper storage conditions, fluctuations in the environment, and microbial activity can hasten spoilage and shorten product lifespan. Traditional methods of assessing food quality primarily rely on manual inspections and sporadic laboratory testing, which may not offer consistent and prompt information throughout storage, transport, and distribution. This paper provides a review of the latest advancements in Internet of Things (IoT), artificial intelligence (AI), automation technologies, and intelligent sensing for monitoring food quality. The review explores IoT-based monitoring systems that utilize sensors, radio-frequency identification (RFID), biosensors, and nano sensors, along with their uses in smart packaging, warehousing, cold-chain management, spoilage detection, food waste reduction, and supply chain traceability. This review also examines the role of machine learning and deep learning in food-quality prediction, spoilage classification, ripening-stage identification, and intelligent decision-making. This thematic review categorises and compares existing studies by sensing technologies, monitored parameters, intelligent analysis techniques, application areas, and intended outcomes. This review explores the significance of quality-management strategies, such as total quality management (TQM), Lean, Six Sigma, and hazard analysis and critical control points (HACCP), in conjunction with developing digital technologies. The assessment points out essential research gaps in areas like sensor reliability, multi-parameter monitoring, generalisation of AI models, interoperability, comprehensive supply-chain integration, secure traceability, automation, and alignment with quality-management systems. Proposed future research directions are presented to aid in the creation of scalable, dependable, and integrated AI-IoT frameworks for predictive and automated management of food quality.

Index Terms - Artificial Intelligence, Automation, Food Quality Monitoring, Internet of Things, Sensors

I. INTRODUCTION

In the contemporary food industry system, ensuring the quality and safety of food is crucial because they have an impact on customer trust, public wellness, financial stability, and the general effectiveness of food distribution networks. Food products can degrade more rapidly and have a shorter usable shelf life due to alterations in the environment, improper storage techniques, bacterial growth, and extended exposure to suboptimal temperature and humidity levels.

Conventional food quality surveillance methods, which rely on analytical testing, repeated sampling, and manual monitoring and inspection, are useful in controlled settings but frequently fall short of offering the real-time insights required to stop contamination, spoilage, and violations of regulations during shipment and storage.

Recent developments in IoT offer a chance to develop an intelligent, real-time food quality monitoring system that improves transparency, productivity, and protection. The creation of an intelligent food supply chain is being aided by new technologies, including AI, ML, RFID, blockchain, edge computing, and wireless communication, in addition to IoT. The utilisation of new technology and sensors for continuous and autonomous food monitoring or spoilage detection has been shown in a number of studies discussed in the current literature.

II. REVIEW METHODOLOGY

The application of the Internet of Things (IoT), artificial intelligence (AI), machine learning, sensing technologies, smart packaging, traceability, and automation in food quality monitoring is examined in this study using a thematic literature review methodology. Studies using sensing technology for continuous or real-time food monitoring are specifically taken into consideration in this study. Existing research utilising new trends for categorisation, ripening-stage identification, spoilage detection, and food quality prediction was also reviewed.

The selected literature was further analyzed according to the technology employed, monitored parameters, application area, intelligent analysis approach, and intended outcome. Particular attention was given to applications across food storage, packaging, transportation, warehousing, cold-chain management, and waste management. The findings were synthesized to identify the current capabilities, limitations, research gaps, and emerging directions for developing intelligent and automated food quality monitoring systems.

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III. IOT BASED FOOD QUALITY MONITORING SYSTEMS

Nath et al. [1] and Popa et al. [2] proposed a cost-effective IoT-based food quality monitoring solution using embedded sensors to collect environmental data (temperature, humidity, gases). Their approach emphasizes real-time alerts to improve food storage, quality and safety logistics. An IoT-driven freshness detection system that monitors gas emissions and environmental parameters, integrated with a mobile app for real-time data access was built by Sanap et al. [3]. A smart stale food detector using gas sensors integrated with Arduino was designed by Murthy et al. [4] which detect food spoilage by monitoring ammonia levels, highlighting the feasibility of low-cost food safety devices. K. Sidhisree et al [5] used Raspberry Pi controller as central system with in-built WiFi connectivity, an LCD for providing real-time display of monitored parameters, DHT11 sensor for temperature/humidity and MQ3/135 sensors to detect gas and ammonia levels respectively. The integration of a wireless sensor based on an inductive-capacitive resonant circuit for monitoring of the quality of dry, packaged food was described by Ee Lim Tan et al. [6] that monitors by placing sensor inside the food and response is remotely detected through a coil connected to a sensor reader.

TABLE I
IoT Based Food Quality Monitoring Systems

STUDY	TECHNOLOGY	PARAMETERS	APPLICATION
Nath et al. Sidhisree et al. Popa et al.	Embedded sensors (DHT11, MQ3/MQ135), Raspberry Pi, Wi-Fi	Environmental parameters (temperature, humidity, gas)	Real-time food quality monitoring
Murthy et al. Sanap et al.	Arduino, mobile app, sensors,	Ammonia Gas, environmental conditions	Freshness and Spoilage detection
Tan et al.	Resonant wireless sensor	Food quality	Packed food monitoring

IV. SENSOR TECHNOLOGIES IN SMART PACKAGING, WAREHOUSE AND TRACEABILITY

Sobhan et al. [7] reviewed IoT-enabled biosensors in food packaging, emphasizing real-time risk detection such as microbial contamination or chemical imbalance, enhancing consumer safety. Puligundla et al. [8] discussed the development of CO_2 sensors embedded in food packaging. These sensors help detect bacterial activity and gas buildup, indicating spoilage in perishable food. A review of advancements in chemical resistive gas sensors used to detect spoilage-related gases, emphasizing their sensitivity and relevance in packaging was done by Shaalan et al. [9]. An IoT-based control system was built by L. K. Hema et al. [10] to manage grain storage conditions, reducing losses due to improper storage or infestations. Alreshidi [11] discussed Smart Sustainable Agriculture (SSA), emphasizing IoT and AI technologies that enable quality monitoring from cultivation to distribution. Nano sensor was integrated by Caon et al. [12] in food packaging, enhancing traceability and food safety through wireless data collection and environmental tracking. Lee et al. [13] proposed an IoT-based warehouse management system with an advanced data analytical approach using computational intelligence techniques to enable smart logistics for Industry. Richards et al. [14], Culler and Long et al. [15] studied challenges in warehouse management and an agile supply chain strategy was coined to maintain smooth inbound and outbound logistics in the changing environment and reduce the total cycle time of a supply chain system.

TABLE II
Sensors for Food Quality Monitoring Systems

SENSOR	PARAMETERS	USAGE
DHT11/DHT22	Temperature and Humidity	Monitoring of Environment and Storage
MQ Gas sensors	CO_2, NH_3 and H_2S	Freshness and Spoilage detection
Biosensor and Nanosensor	Biological and chemical indicators	High sensitivity potential to detect pathogens, toxins and pesticides

V. INTEGRATION OF ARTIFICIAL INTELLIGENCE IN FOOD QUALITY MONITORING

Occhiuzzi et al. [16] introduced RFID-based ripening monitoring for fruits. Their machine learning-enhanced system accurately detected ripening stages, optimizing logistics. Integration of IoT and blockchain by Iftekhar et al. [17] ensured tamper-proof food safety data. Their architecture supports secure and traceable food handling throughout the supply chain. Ahmed and Hassanien [18] applied machine learning models to predict food quality from collected environmental and sensor data, improving predictive accuracy in the supply chain. IoT and deep learning were integrated by Jagadeesan et al. [19] to create a food hygiene monitoring model that predicts spoilage and contamination risks, showing high accuracy in classification tasks. Almassar and Khasawneh [20] reviewed AI-IoT integration for household food replenishment and broader food monitoring. Their findings support predictive consumption and minimize waste using intelligent forecasting.

TABLE III
Artificial Inteeligence for Food Quality Monitoring Systems

STUDY	APPROACH	USAGE
Occhiuzzi et al.	ML + RFID	Ripening detection
Ahmed & Hassanien	ML	Quality prediction
Jagadeesan et al.	Deep learning + IoT	Hygiene/ Risk Classification
Gull et al.	ML + eNose	Waste/ spoilage classification

VI. SPOILAGE DETECTION, SUPPLY CHAIN AND WASTE MANAGEMENT

Preethichandra et al. [21] introduced polymer-based sensors capable of detecting ammonia and hydrogen sulfide for meat and fish spoilage. Prilliadi [22] combined IoT with spoilage detection to develop an efficient food waste management system. The work contributes to environmental sustainability by identifying spoiled items early. A smart eNose system was

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proposed by Gull et al. [23] using gas sensors and machine learning to classify waste and detect spoiled food, contributing to automated waste management. Parvez et al. [24] implemented a food wastage management framework integrated with sensors that identify unused or expired products, guiding timely redistribution or disposal. Robust solution for the continuous monitoring and management of perishable food products was given by Rani, N. U [25] incorporating temperature and gas sensors, Food Spoilage Detection and Alerting System using IoT was designed to detect early signs of spoilage, enabling timely intervention to prevent food waste and its safety. Ambili et al. [26] proposed an automatic food quality evaluation system for sorting and grading of fresh food and old food due to storage or chemical changes. An IoT-based risk monitoring system for managing cold supply chain risks has been developed by T.P. da Costa et al. [27] that uses IoT sensors to monitor humidity, temperature, and other environmental factors affecting food quality during transportation and storage and then providing real time alert to relevant authorities if any deviations from the optimal conditions are detected.

TABLE IV

Spoilage Detection, Supply Chain and Waste Management

STUDY	APPROACH	USAGE
Preethichandra et al.	Polymer-based sensors for NH_3 and H_2S	Detection of gases for deterioration of meat and fish products
Prilliadi et al. Gull et al. Rani et al.	IoT, Smart electronic nose (eNose), gas sensors , ML	Identification of spoiled food to support food-waste management and sustainability
Parvez et al.	Sensor-based product usage and expiry-related information	Identification of unused/expired food to support appropriate redistribution and disposal decisions
Ambili et al.	Sensors to detect changes in storage and chemical conditions	Automatic evaluation and sorting/grading of fresh and older food products
T. P. da Costa et al.	IoT-based risk monitoring of environmental conditions	Real-time monitoring of cold-chain risks during transportation and storage, with alerts when deviations occur

VII. QUALITY MANAGEMENT SYSTEM IN FOOD INDUSTRY

Partalidou et al. (2020) [28] reported that TQM, Lean and Six Sigma positively affect the financial performance in food companies. Meanwhile, Zainal et al. (2018) [29] showed that the TQM, Lean and Hazard Analysis Critical Control Point significantly influenced the production performance. Danyen & Callychurn (2015) [30] indicated that successful implementation of TQM in Mauritian food manufacturing companies had a significant and positive impact on operational performance and quality performance. Hong et al., (2020)[31] mentioned that quality management has a significant positive effect on the quality safety performance and sales performance. Pipatprapa et al. (2016)[32] indicated that quality management has a significantly positive effect on environmental performance of the enterprise, as well as green performance.

TABLE V

Quality Management System in food industry

STUDY	OUTCOMES BY USING QM APPROACH
Partalidou et al. Zainal et al.	TQM, Lean, Six Sigma and HACCP have a positive influence on the financial and production performance of food production companies.
Danyen & Callychurn	Implementation of TQM increased operational and quality performance in food manufacturing.
Hong et al. Pipatprapa et al.	Quality-management practices affect quality, safety, sales and environmental performance in food industry.

VIII. RESEARCH GAPS AND FUTURE DIRECTIONS

Although IoT, AI, sensor technologies, smart packaging, and intelligent food-monitoring systems have shown great promise, a number of obstacles and restrictions still exist, according to the evaluation of previous research. Sensor dependability, multi-parameter monitoring, supply-chain integration, AI model generalisation, traceability, automation, and connection with quality-management procedures are the primary areas where gaps have been found. Table 6 summarises the key research gaps and related future directions based on the results of the examined literature.

TABLE VI

Research Gaps and Future Directions in Intelligent Food Quality Monitoring

Research Area	Existing Focus in Literature	Identified Research Gap	Future Direction
Sensors	Temperature, humidity, gases and other sensors	Accuracy and reliability	Calibration and multi-sensor systems
Food-quality monitoring	Real-time monitoring and alerts	Limited comprehensive assessment	Multi-parameter intelligent monitoring
AI/ML	Prediction, classification and spoilage detection	Limited generalization	Robust models across food types and conditions
Smart packaging	CO_2, gas and nanosensor-based monitoring	Need for broader integration	Intelligent connected packaging
Supply chain	Storage, transportation and cold-chain monitoring	Fragmented monitoring	End-to-end monitoring
Automation	Alerts and automated evaluation	Limited automated intervention	AI-driven decision and action
Traceability	RFID and blockchain applications	Need for integrated traceability	IoT + AI + secure traceability
Quality management	TQM, Lean, Six Sigma and HACCP	Limited integration with real-time IoT	IoT-enabled quality management
Food waste	Spoilage and expired-food detection	Greater emphasis on prevention needed	Predictive spoilage and waste reduction

IX. CONCLUSION

The paper emphasises how IoT, automation, intelligent sensing, and artificial intelligence are becoming increasingly important for food quality surveillance. Studies already

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conducted show that IoT-based systems using temperature, humidity, gas, RFID, biosensors, and other cutting-edge technology can facilitate real-time warnings, spoilage/ripening-stage detection, ongoing surveillance, and better food product management.

The studied literature also shows that these technologies may be used in smart packaging, warehousing, cold-chain management, supply-chain monitoring, traceability, and food-waste management, in addition to individual food-monitoring systems. An organisational foundation for enhancing food quality, safety, operational performance, and sustainability is further provided by quality-management techniques including TQM, Lean, Six Sigma, and HACCP.

However, the review shows that there are still a number of issues that need to be resolved, especially with regard to secure traceability, end-to-end supply-chain integration, generalisation of AI models, sensor reliability, integration of multiple sensing parameters, and integration of real-time technological systems with established quality-management practices. In order to overcome these obstacles, integrated and intelligent systems that can integrate sensing, data transmission, AI-based analysis, and automated decision support must replace isolated monitoring methods.

All things considered, the combination of IoT, AI, and automation offers a promising route toward more responsive food businesses and intelligent food-quality monitoring. Future studies should concentrate on creating dependable, scalable, and interoperable frameworks that can facilitate automated intervention, real-time monitoring, predictive quality assessment, traceability, and the reduction of food waste at various food supply chain stages.

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