RESEARCH ARTICLE OPEN ACCESS

Use of Machine Learning and Artificial Intelligence in Food Spoilage Detection

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ABSTRACT
Identification of spoiled food is crucial for maintaining food safety and lowering food waste. This paper explores the integration of machine learning (ML) and artificial intelligence (AI) in food spoilage detection, highlighting and supplying recent advances and implications for conventional methods of spoiled food detection and compares IoT-enabled systems and the sensor era. Furthermore, the paper explores research on the usage of ML and AI strategies for food spoilage prediction, which include electronic nose systems, gas sensor arrays, and neural networks and includes techniques for modelling analysis with experimental consequences and performance assessment of the environment. The study highlights the ability of ML and AI to improve food safety and waste reduction efforts. Finally, it indicates future study directions for further applications of this generation in food waste assessment. Bringing collectively relevant literature and methodologies, this evaluation affords insights into the modern repute and destiny potentialities of ML and AI in food waste assessment.
Keywords – Machine learning, artificial intelligence, food spoilage detection, IoT, sensor technologies, predictive modelling, food safety, food waste reduction.

Date of Submission: 04-04-2024 Date of acceptance: 15-04-2024

I. INTRODUCTION

Food spoilage detection is an important issue of food safety management systems, ensuring that clients acquire safe and extremely good products at the same time as also minimizing food waste. Traditional methods of detecting spoilage depend upon sensory assessment, which may be subjective and at risk of errors. With the fast development of era, in particular within the fields of machine learning (ML) and artificial intelligence (AI), there was a paradigm shift in how food spoilage detection is approached. Food spoilage poses a huge challenge to food safety and sustainability, contributing to both economic losses and environmental degradation. Detecting and mitigating spoilage promptly is critical for making sure food is nice, decreasing waste, and safeguarding public fitness. In recent years, there has been a developing hobby in leveraging superior technology, mainly machine learning (ML) and artificial intelligence (AI), to design food spoilage detection processes.

Traditional techniques of detecting food spoilage regularly depend upon human sensory evaluation or basic sensor technologies. However, those strategies may be subjective, time-eating, and susceptible to errors, especially in big-scale food manufacturing and distribution networks. With the advent of IoT-enabled systems, biosensors, and nanomaterials, there has been a paradigm shift towards actual-time monitoring of food quality and spoilage throughout the supply chain. The detection of food spoilage has good-sized implications for public fitness, financial efficiency, and environmental sustainability. Foodborne illnesses as a consequence of spoiled food can lead to severe health consequences, highlighting the paramount importance of accurate and timely spoilage detection.

Additionally, food waste poses a good-sized task, with billions of tons of food discarded annually, exacerbating environmental degradation and financial inefficiencies during the food delivery chain.

ML and AI technology offer modern methods to improving food spoilage detection techniques. By leveraging widespread datasets and advanced algorithms, these technologies can analyze complicated patterns and correlations to pick out signs of spoilage more efficiently than conventional methods. ML algorithms can analyze ancient records to predict future spoilage events, even as AI systems can autonomously screen food fine in actual-time, facilitating early detection and intervention. This evaluation paper explores the combination of ML and AI technologies in food spoilage detection and its implications for food safety and waste reduction. By synthesizing insights from current studies and seminal research in the area, this paper ambitions to explain the potential of ML and AI in revolutionizing food spoilage detection approaches. Ultimately, the integration of those technology holds remarkable promise for boosting food safety requirements and mitigating the environmental and economic influences of food waste. This paper aims to offer a complete evaluate of the mixing of ML and AI techniques in food spoilage detection.

II. LITERATURE REVIEW

The study by Damdam et al. [1] introduces an IoT-enabled electronic nose system designed for beef quality monitoring and spoilage detection, addressing the critical need for improved food safety and quality assurance in the meat industry. The architecture of the IoT-enabled monitoring system (IoTMS) as retrieved from in fig. no. 1 from [1] is given below:

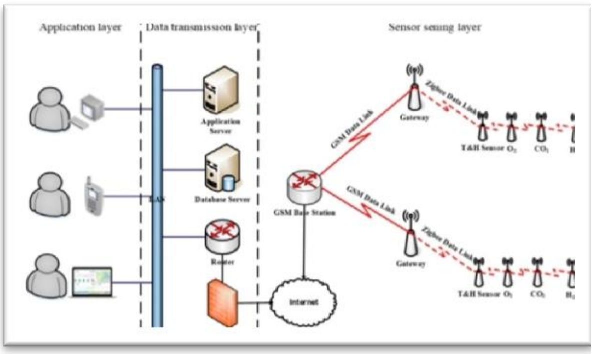

Fig No. 1: The architecture of IoT-enabled monitoring system (IoTMS) [1]

The paper highlights the significance of actual-time tracking in preventing financial losses and fitness dangers related to spoiled meat merchandise. By integrating IoT technology with electronic nose sensors, the device permits far off and continuous tracking of unstable organic compounds emitted at some stage in beef spoilage, facilitating early detection and intervention. The implementation of such superior monitoring systems can revolutionize food nice control practices, no longer only inside the red meat industry but also across different perishable food sectors, contributing to superior food safety and decreased waste at some point of the supply chain. The advantages and limitations of e-nose application in food assessment, table no. 1, as retrieved from [1] is given below:

Table No. 01: Advantages and Limitations of e-nose applications

Samples	Objectives	Technology Application	Advantages	Limitations
Meat	Quality Spoilage detecting	Quartz crystal microbalance (QCM)	High sensitivity	High Cost
Flavor and aroma, Meat flavor	Identification and classification	Neotronics Olfactory Sensing Equipment and QCM	Short response time Low cost	Sensor drift
Beef	Freshness identification	Electronic nose only	Quick response High sensitivity	High power consumption
Palm oil	Mixture identification	Electrochemical sensors system	Universal application High sensitivity	Large size High power consumption
Goat milk	Adulteration Detection	Semiconductor sensors (MOS)	Low cost Low power consumption	Short life span
Red meat	Spoilage classification	Electronic nose and E-tongue	Quick response Low cost	High power consumption
Litchi	Freshness evaluation	Electronic nose (E-nose) only	Rapid and non-destructive	Sensor drift High power consumption

In the paper, Bhatlawande et al. [2] discover the transformative capability of clever food packaging by integrating biosensors, the Internet of Things (IoT), and nanomaterials. The authors underscore the importance of advancing food packaging technologies to decorate food safety, greatness, and sustainability. They highlight the position of biosensors in detecting various parameters consisting of temperature, humidity, and fuel composition within packaging, imparting actual-time tracking skills. Additionally, the combination of IoT allows far off tracking and communique of packaging records, offering insights into product conditions in the course of the supply chain. Furthermore, the incorporation of nanomaterials enhances packaging residences including barrier houses, antimicrobial pastime, and mechanical electricity. The study emphasizes the need for collaborative efforts between researchers, enterprise stakeholders, and regulatory bodies to free up the full potential of smart food packaging technology in addressing global food safety and sustainability challenges. Classification of Intelligent Packaging, as in fig. no. 2, as retrieved from [2] is given below:

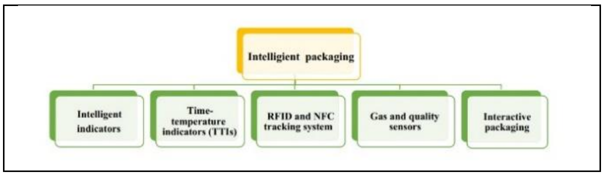

Fig No. 2: classification of intelligent packaging [2]

Gillespie et al. [3] investigate actual-time anomaly detection in cold chain transportation through the utilization of Internet of Things (IoT) technology. The authors emphasize the critical importance of preserving the integrity of the cold chain to ensure the exceptional protection of perishable items all through transportation. They talk about the implementation of IoT-enabled tracking systems, which permit non-stop monitoring and evaluation of temperature and other environmental parameters along the cold chain. By leveraging advanced records analytics strategies, which include anomaly detection algorithms, the device can discover deviations from ideal situations in real-time, permitting proactive intervention to save you spoilage and ensure the product is first-rate. The examination highlights the capacity of IoT technology to beautify the performance and reliability of cold chain logistics, ultimately contributing to the sustainability of the food supply chain and decreasing food waste.

Saravanan [4] delves into the intricate problem of food waste control, emphasizing sustainability and the imperative to feed all. The study navigates through solutions geared toward mitigating food waste, acknowledging its full-size environmental and social influences. By offering techniques to optimize food utilization and decrease waste generation, Saravanan advocates for a holistic approach to food waste management, encompassing numerous stakeholders and sectors of the food deliver chain. Through innovative answers and collaborative efforts, the take a look at aims to pave the manner closer to a greater sustainable and equitable food system.

Jain [5] offers a comprehensive evaluate that specialize in the character and causes of decay in fruits and vegetable, shedding light on the complexities of submit-harvest dealing with and storage practices. The study examines various factors contributing to the deterioration of sparkling produce, including physiological adjustments, microbial spoilage, and environmental stressors. By elucidating the underlying mechanisms of deterioration, Jain underscores the importance of enforcing effective maintenance and dealing with strategies to prolong the shelf existence and maintain the pleasant of end result and vegetables. The insights furnished on this assessment provide treasured guidance for stakeholders throughout the agricultural and food industries looking for to mitigate put up-harvest losses and improve food safety.

In their systematic assessment, da Costa et al. [6,7] explore actual-time monitoring technology and their potential application in reducing food loss and waste during the food supply chain. The look at synthesizes present literature on key factors of food supply chains and IoT technologies, highlighting their roles in enhancing traceability, transparency, and efficiency. By analyzing the contemporary panorama of actual-time tracking technologies, the authors perceive possibilities for integrating these improvements into food delivery chain management practices. Through strategic deployment and integration with present infrastructure, actual-time monitoring technology has the potential to mitigate food loss and waste, ultimately contributing to a more sustainable and resilient food machine.

Singha et al. [8] introduce IntelliStore, an modern IoT and AI-based intelligent garage tracking device designed particularly for perishable food gadgets. The paper outlines the structure and functionalities of IntelliStore, which leverages IoT sensors and AI algorithms to reveal environmental situations consisting of temperature, humidity, and air first-class inside garage centers. By offering actual-time insights and predictive analytics, IntelliStore permits stakeholders to optimize garage situations, reduce spoilage, and expand the shelf existence of perishable food gadgets, thereby contributing to reduced food waste and progressed food protection.

Nastiti et al. [9] explore the category of freshness ranges and prediction of gas evolution from chook meat in the course of storage at room temperature. The have a look at utilizes sensor technologies to locate adjustments in gas composition, particularly NH3 and H2S, which might be indicative of meat spoilage. Through information analysis and predictive modelling, the authors display the feasibility of appropriately predicting freshness levels and spoilage development in bird meat, providing valuable insights for enhancing garage practices and minimizing food waste.

The look at [10] explores the application of electronic noses and tongue-based totally sensor systems in food science. The authors spotlight the flexibility of these sensor technologies in detecting various unstable compounds and flavor profiles, which can be indicative of food great and freshness. Through a comprehensive assessment of literature and case research, Kaur et al. Exhibit the capability of electronic noses and tongue-based sensors in enhancing food protection and great evaluation processes throughout diverse food categories.

Ahmed and Hassanien [11] recommend a system getting to know-based method to optimize food satisfactory prediction. The paper outlines diverse ML algorithms and strategies that may be hired to research food satisfactory parameters and are expecting product attributes together with freshness, shelf life, and dietary content. Through experimental validation and comparative evaluation, the authors elucidate the efficacy of ML models in appropriately predicting food best, providing treasured insights for optimizing food processing and distribution approaches.

Rivai et al. [12] inspect the discrimination of durian ripeness stages the use of fuel sensors and neural networks. The observe employs fuel sensor arrays to detect risky organic compounds emitted with the aid of durian fruit at exclusive ripeness ranges. Through the implementation of neural community models, the authors show the feasibility of appropriately classifying durian ripeness ranges based on gas sensor facts, providing capacity applications for optimizing fruit harvesting and post-harvest handling processes.

Pallavi et al. [13] introduce an IoT and cell app-primarily based food spoilage alert device designed to beautify food protection and decrease waste. The paper discusses the structure and functionalities of the machine, which makes use of IoT sensors to screen environmental conditions and detect spoilage events in actual-time. Through the integration of a cell application, stakeholders obtain well timed signals and guidelines for mitigating food spoilage, thereby enhancing food control practices and minimizing losses in the course of the deliver chain.

Nowshad and Khan [14] delve into the application of electronic tongue technology for food safety and quality assessment. The paper discusses the principle of electronic tongue systems, which mimic the human gustatory system to analyze taste profiles and detect adulteration or contamination in food products. Through a review of existing research and case studies, the authors showcase the versatility and accuracy of electronic tongue technology in assessing food quality attributes such as taste, texture, and authenticity. The study underscores the potential of electronic tongue systems as rapid and reliable tools for ensuring food safety and quality control in various food industries.

Sahu et al. [15] present the development of a non-destructive food quality monitoring system based on machine learning and edge IoT technologies using Raspberry Pi. The paper outlines the architecture and functionalities of the system, which leverages ML algorithms to analyze sensory data captured by IoT sensors. Through experimental validation and performance evaluation, the authors demonstrate the feasibility and effectiveness of the system in accurately assessing food quality parameters such as freshness, ripeness, and spoilage. The study highlights the potential of ML and IoT-based solutions for enhancing food quality control practices and reducing food waste in both industrial and household settings. Environmental conditions such as temperature and humidity, while electronic nose devices analyze volatile compounds emitted by salmon to determine freshness. Through experimental trials and sensory evaluations, the authors demonstrate the reliability and accuracy of the combined IoT and electronic nose system in assessing salmon quality. The findings highlight the potential of these technologies for ensuring food safety and quality throughout the cold storage process, particularly in the seafood industry where freshness is paramount.

Farooq et al. [18] provide a comprehensive review of smart IoT-based farming systems and their applications in agriculture. The paper discusses various IoT technologies and sensors deployed in smart farming solutions to monitor environmental conditions, soil moisture, crop health, and livestock behavior. Through a synthesis of existing literature and case studies, the authors highlight the transformative impact of IoT-based farming systems in improving agricultural productivity, resource efficiency, and sustainability. The review underscores the potential of smart IoT-based farming solutions to address challenges such as climate change, food security, and resource scarcity, paving the way for a more resilient and efficient agricultural sector.

By reviewing the current state of ML and AI applications in food spoilage detection, this paper seeks to identify opportunities for further research and implementation efforts. Through a multidisciplinary approach, we aim to contribute to the ongoing efforts to enhance food safety, reduce food waste, and promote sustainability in the food industry.

Ck et al. [16] propose an IoT-based solution for alerting food spoilage in refrigerators. The paper discusses the development of a system that utilizes IoT sensors to monitor temperature and humidity levels inside refrigerators. When abnormal conditions indicative of spoilage are detected, the system sends alerts to users via a mobile application, prompting timely intervention to prevent food waste. Through experimental validation and usability testing, the authors demonstrate the effectiveness of the system in alerting users to potential spoilage events, thereby improving food management practices and reducing waste in household refrigerators.

Feng et al. [17] evaluate the effectiveness of IoT-enabled monitoring and electronic nose technology for assessing salmon freshness during cold storage. The study utilizes IoT sensors to monitor.

III. ARTIFICIAL INTELLIGENCE AND MACHINE LEARNING TECHNOLOGIES

Following are a few artificial intelligence and machine learning technologies.

1. Internet of Things (IoT) Sensors: IoT sensors play a crucial role in collecting real-time data on environmental conditions such as temperature, humidity, and gas levels within food storage environments. These sensors enable continuous monitoring and provide valuable insights into changes that may indicate spoilage.

2. Artificial Intelligence (AI): AI encompasses various techniques such as machine learning, deep learning, and neural networks that can analyze complex datasets and identify patterns indicative of food spoilage. AI algorithms can process large volumes of data efficiently and make predictions or recommendations based on historical trends and current observations.

3. Machine Learning (ML): ML algorithms enable computers to learn from data and make predictions without explicit programming. In the context of food spoilage detection, ML models can be trained on datasets containing information about food properties, storage conditions, and spoilage events to identify patterns and anomalies associated with deteriorating food quality.

4.Image Recognition: Image recognition technology allows computers to analyze visual data and identify patterns or objects within images. In food spoilage detection, image recognition algorithms can analyze photographs or videos of food products to detect visual cues associated with spoilage, such as discoloration, mold growth, or physical damage.

5. Electronic Nose (E-Nose) Technology: E-Nose devices are equipped with arrays of chemical sensors that can detect volatile organic compounds (VOCs) emitted by food products as they undergo spoilage. AI and ML algorithms can analyze the sensor data to identify unique odor profiles associated with different stages of spoilage, enabling early detection and intervention.

6. Electronic Tongue (E-Tongue) Systems: E-Tongue systems consist of sensor arrays capable of detecting taste and flavor attributes in food samples. By analyzing the electrical signals generated by these sensors, AI algorithms can identify changes in taste profiles that may indicate spoilage or contamination, providing additional insights into food quality.

7. Data Analytics Platforms: Advanced data analytics platforms equipped with AI and ML capabilities can process and analyze large volumes of heterogeneous data from diverse sources, including IoT sensors, laboratory tests, and historical records. These platforms enable comprehensive analysis and visualization of food spoilage trends, facilitating data-driven decision-making and proactive risk management.

8. Blockchain Technology: Blockchain technology offers a secure and transparent way to record and track the entire lifecycle of food products from farm to fork. By leveraging blockchain-based food traceability systems, stakeholders can ensure transparency, accountability, and authenticity throughout the supply chain, enabling rapid identification and containment of spoilage incidents.

IV. RESULTS AND DISCUSSION

The literature review reveals a diverse range of technologies and methodologies employed in the field of food spoilage detection and quality monitoring. Studies introduce innovative IoT-enabled electronic nose systems for beef quality monitoring, explore the integration of biosensors and IoT in smart food packaging, and focuses on real-time anomaly detection in cold chain transportation using IoT technology. Other studies investigate classification and prediction techniques for freshness levels and gas evolution in perishable foods as well as the application of electronic noses and tongue-based sensor systems in food science.

The findings indicate a growing interest in leveraging advanced technologies such as IoT, artificial intelligence (AI), and sensor systems to enhance food safety and quality control processes. These technologies offer real-time monitoring capabilities, enabling early detection of spoilage and ensuring compliance with quality standards throughout the food supply chain. Studies focusing on machine learning-based approaches highlight the potential for predictive modelling in optimizing food quality prediction, thus improving efficiency in food processing and distribution.

Furthermore, the integration of IoT and AI-based solutions offers promising avenues for intelligent storage monitoring and food spoilage alert systems. Such systems not only minimize food wastage but also contribute to enhancing food security by ensuring the timely detection and mitigation of spoilage events. Additionally, advancements in electronic nose and tongue technologies provide rapid and reliable methods for assessing food quality attributes, thereby facilitating effective quality assurance measures.

V. CONCLUSION

In conclusion, the literature reviewed underscores the significance of employing cutting-edge technologies for food spoilage detection and quality monitoring. The integration of IoT, AI, sensor systems, and machine learning algorithms offers innovative solutions to address challenges related to food safety, waste reduction, and quality assurance. Future research in this field should focus on further enhancing the accuracy, scalability, and accessibility of these technologies to ensure their widespread adoption across various sectors of the food industry. By leveraging these advancements, stakeholders can work towards achieving greater sustainability, efficiency, and safety in food production, distribution, and consumption processes.

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