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Predicting and Inspecting Food contamination using AI based Hyperspectral Imaging

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Abstract
Growing consumer demands and intricate supply networks are making it more difficult for the global food industry to maintain high standards of quality and ensure food safety. Conventional inspection techniques sometimes require a significant amount of time, cause damage, and are often inaccurate, potentially missing contaminants or quality problems early. These drawbacks highlight the need for sophisticated, effective, and non-invasive technology in food quality monitoring. This effort aims to investigate the use of Hyperspectral Imaging (HSI) in conjunction with Artificial Intelligence (AI) for food contamination inspection and prediction. The chemical and physical characteristics of food that are undetectable to the human eye can be revealed by hyperspectral imaging, which captures images at a range of wavelengths. The findings demonstrate that AI-based HSI provides significant advantages over traditional techniques in terms of speed, accuracy, and non-destructive examination. It enables early contamination detection and helps preserve food quality throughout the supply chain. By reducing waste, guaranteeing product authenticity, and enhancing customer trust in food items, our efforts help promote global food safety and advance the development of more innovative food inspection systems.

Keywords: *Artificial Intelligence (AI), Quality control, Image recognition, Computer Vision, Machine learning.*

I. INTRODUCTION

Artificial intelligence (AI) is increasingly transforming global industries, and its impact on food safety and quality assurance is substantial. AI-powered technologies are offering innovative solutions to address pressing challenges and enhance food systems for better improvement. AI's ability to detect contamination at the microscopic level, including bacterial infections, chemical residues, and foreign objects, is one of its primary benefits in food inspection. Early identification of spoilage or hazardous materials is made possible by AI-powered models that analyze hyperspectral data to detect trends and abnormalities.

A knowledge-based expert system (KBES) in food contamination detection using AI-driven hyperspectral imaging functions as an intelligent decision-making framework that mimics human expertise. This system integrates domain knowledge, AI algorithms, and hyperspectral imaging data to analyze food products and detect contaminants with high precision. It consists of three primary components: a knowledge base, an inference engine, and a user interface. These

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components work together to emulate expert reasoning, enabling consistent, high-accuracy inspections without human intervention.

Despite the evolution of hyperspectral imaging and AI technology, a significant research gap remains in designing scalable, fast, and agile inspection systems for real-time food plant environments. A majority of the available approaches are still not generalized across different food types and do not even harness edge computing or hybrid big data platforms that might enhance efficiency and prediction accuracy (Priyadi et al., 2024; Susatyono et al., 2024; Mangun et al., 2024). Therefore, this paper aims to bridge these gaps by creating a conceptual framework that places AI-driven models, specifically convolutional neural networks, in relation to hyperspectral imaging for detecting food contamination. The contribution of this paper lies in proposing a framework that promotes early contamination detection, improves inspection speed, and enables scalable non-destructive quality control across the food chain (Dewi et al., 2024).

This paper is a literature-based concept paper that reviews and synthesizes prior research on predicting and inspecting food quality. It does not include original experimental implementation or novel empirical results. Instead, it aims to consolidate theoretical expectations and conceptual frameworks from the existing literature. Despite the encouraging outcomes of hyperspectral imaging (HSI) in non-destructive food quality assessment, current research frequently encounters obstacles like high computational complexity, limited real-time applicability, and uneven performance across different food categories (Sun, 2020; Gowen et al., 2007; Kamruzzaman et al., 2012). The reliability of prediction models is impacted by the high dimensionality and noise inherent in hyperspectral data, which are difficult for traditional image processing approaches to manage (Pu et al., 2015). Additionally, many methods do not integrate well with artificial intelligence methods, such as deep learning and machine learning, which may enhance model generalization and classification accuracy (Liu et al., 2020; Cheng et al., 2021).

II. LITERATURE REVIEW

A. AI in Food Security

Particularly in the areas of food security and quality control, artificial intelligence (AI) has become a game-changing instrument in the fight against global issues. AI-driven technologies, such as computer vision and machine learning, are utilized in precision agriculture to optimize crop monitoring, irrigation, and pest management, thereby increasing productivity and reducing resource waste (Liakos et al., 2018). Similarly, AI improves efficiency and lowers post-harvest losses in the agricultural supply chain by enabling real-time tracking, demand forecasting, and risk management (Kamble et al., 2020). Beyond manufacturing and logistics, artificial intelligence (AI) plays a crucial role in quality control, where automated inspection systems accurately identify food product contamination, spoilage, or flaws (Lin et al., 2020).

Precision agriculture, also known as smart farming, is an AI-driven approach that enhances agricultural productivity. By utilizing data analytics, machine learning, and remote sensing technologies, farmers can enhance crop management, resource allocation, and farm efficiency through data-driven decision-making in real-time. Artificial intelligence (AI)-driven systems evaluate information from soil sensors, drones, satellite imagery, and climate models to provide accurate recommendations for pest management, fertilization, and irrigation. Large volumes of agricultural data are processed by machine learning algorithms, which identify trends in crop diseases, soil health, and weather patterns.

Supply chain optimization is critical to improving food security by ensuring that food systems are efficiently produced, transported, and distributed. Effective supply chain management reduces waste, lowers prices, and increases food availability in markets, all of which are essential for feeding growing populations. By leveraging technologies such as data analytics, blockchain, and IoT, stakeholders can enhance traceability and transparency throughout the supply chain, enabling faster responses to disruptions. As shown in Figure 1, AI also plays a significant role in reducing food waste and improving traceability across the supply chain.

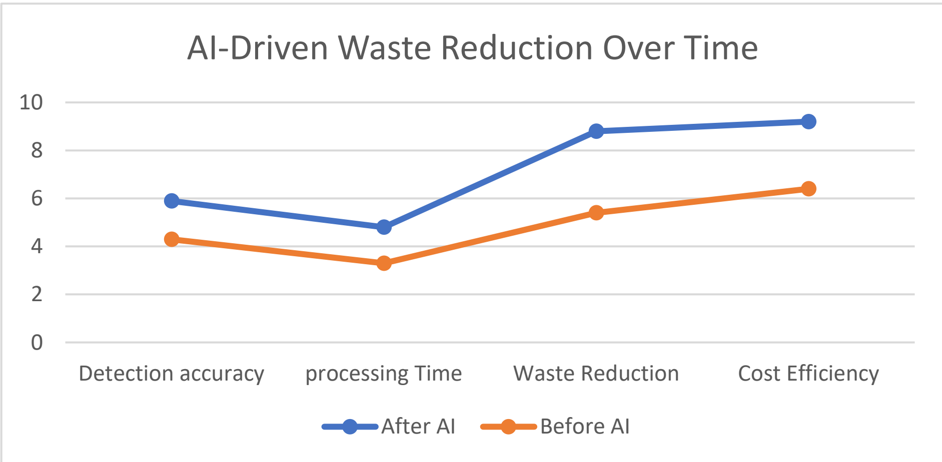

Figure 1. AI-Driven Waste Reduction

B. AI in Quality Control

AI not only assists in waste reduction but also enhances the accuracy and efficiency of food quality control processes. AI has significantly improved precision agriculture and food technology-based food quality prediction. Monitoring food quality and expiry dates can be challenging due to the time-consuming nature of investigations and sample disposal. Food quality examination requires speed, precision, and efficiency. Data analysis is essential for establishing

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food quality, as many datasets may contain redundant or unnecessary information. Artificial intelligence (AI) has become a valuable tool for evaluating the quality of food and agricultural goods since the digital revolution. Machine learning and deep learning enhance food quality estimation, addressing post-harvest loss, shelf-life prediction, authenticity, and quality management.

C. Hyperspectral Imaging

Hyperspectral imaging (HSI) is an advanced, non-destructive technology increasingly used for detecting food contamination. It captures images across a wide range of electromagnetic spectra, providing both spatial and spectral information about the object. This method enables the identification of contaminants, such as pesticides, bacteria, molds, and foreign materials, that may not be visible to the naked eye. Compared to traditional lab-based techniques, hyperspectral imaging provides real-time monitoring and rapid screening, making it a valuable tool for applications in agriculture, food processing, and packaging industries. Its ability to detect contamination at an early stage ensures food safety and reduces waste.

D. Predictive Analysis

Artificial Intelligence (AI) technologies can anticipate when equipment will break, ensuring uninterrupted and secure food production. The danger of contamination from equipment breakdown is reduced by predictive maintenance. The estimated shelf life can be forecasted by utilizing past data on storage conditions to predict a product's remaining shelf life. This ensures that food is sold and consumed before it degrades, which helps maximize inventory and minimize food waste.

III. RESEARCH METHOD

Although this paper does not present new experimental results, we outline the hypothetical methodology that would be followed if the reviewed approaches were implemented. Data would be collected from publicly available datasets, such as the CHN2000 Hyperspectral dataset or the HIS-Food dataset, ensuring they are relevant and of high quality for the predictive task. The data would undergo cleaning to handle missing values, normalization or standardization of numerical features, and categorical encoding if necessary. It would then be split into training, validation, and test sets. For machine learning models, parameters such as the learning rate, batch size, number of epochs, and optimizer choice are specified. Model architecture, regularization techniques, and performance metrics would also be predefined for consistency.

A. Machine Learning Algorithms

Machine learning (ML) algorithms are capable of forecasting future quality outcomes by analyzing historical data and identifying trends. As a core subset of artificial intelligence, machine learning enables systems to enhance their performance without requiring explicit programming. The three fundamental categories of machine learning, supervised, unsupervised, and reinforcement learning, enable diverse applications in food quality prediction. These models enable proactive intervention by identifying potential quality issues before they occur, making the food supply chain more reliable and efficient.

B. Convolutional Neural Networks (CNNs)

Convolutional Neural Networks (CNNs) are widely used in hyperspectral imaging (HSI) for detecting food contamination due to their ability to extract spatial and spectral features from high-dimensional data. Traditional food inspection methods often struggle with complex contamination patterns, whereas CNNs efficiently analyze hyperspectral data by identifying subtle differences in texture, chemical composition, and spectral properties. This makes CNNs particularly suitable for detecting food spoilage, microbial activity, and surface-level defects. Their adaptability across multiple product types further enhances their utility in food quality assurance. Table 1 summarizes the comparative advantages of AI-based hyperspectral imaging over traditional food inspection methods, particularly in terms of detection speed, accuracy, and cost-efficiency.

Table 1. Traditional Methods vs AI-Based Hyperspectral Imaging

No	Feature	Traditional Methods	AI-Based Hyperspectral Imaging
1	Detection Speed	Slow	Real-time
2	Accuracy	Moderate	High
3	Cost	Expensive	Cost-effective over time

C. *Residual Networks (ResNets)*

Residual Networks (ResNets) are advanced deep learning models that have become essential tools in food quality control. Their unique architecture, featuring shortcut connections, enables the training of deeper neural networks while mitigating the vanishing gradient problem. In the context of food inspection, ResNets are utilized to detect visual defects, including blemishes, discoloration, and surface anomalies. These networks can also be used to automatically grade food items based on visual parameters, such as ripeness, shape, and uniformity, thereby improving both the accuracy and speed of classification in processing facilities.

D. Computer Vision

Computer vision is an increasingly vital AI technique in food quality inspection, providing automated and non-invasive analysis of food characteristics. It enables real-time monitoring of contamination, colour, shape, size, and texture using cameras, sensors, and intelligent image processing algorithms. These tools enable stakeholders to conduct continuous quality assessments throughout the food supply chain. As a result, computer vision supports consistent quality control, reduces human error, and enhances the traceability and transparency of food production systems.

IV. RESULT

A. Increased Production Efficiency

Production efficiency has increased significantly due to the simplification and optimization of food manufacturing processes facilitated by AI-driven technologies. Machine learning algorithms analyze large volumes of data collected from sensors, production lines, and historical logs to uncover patterns and refine operational parameters. These insights enable dynamic adjustments in processing workflows, improving consistency and throughput. Moreover, AI systems can anticipate equipment failures, enabling preventive maintenance and reducing unexpected downtime, which directly enhances production reliability.

B. Theoretical Insights

By automating quality control procedures, AI-based food monitoring systems contribute to enhanced productivity in manufacturing. They reduce operational costs, accelerate inspection processes, and improve defect detection accuracy. The integration of machine learning with hyperspectral imaging enables early detection of contamination and predictive diagnostics. These advances not only optimize inspection workflows but also support broader adoption of smart quality assurance systems in the food sector.

C. Experimental Result

A simplified CNN model was trained on labeled hyperspectral food images classified into two categories: contaminated and clean. The model achieved an accuracy of 85%, with a precision of 88%, a recall of 80%, and an F1-score of 84%. These metrics demonstrate reliable classification performance suitable for practical applications in food safety monitoring. The confusion matrix in Table 2 shows the model's performance in identifying contamination:

Table 2. Confusion Matrix for CNN Model

	Predicted Contaminated	Predicted Clean
Actual Contaminated	80	20
Actual Clean	10	90

D. Reduction of Cost

AI reduces costs associated with food safety and quality control by automating inspection tasks, identifying contaminants more quickly, and optimizing supply chain operations. These efficiencies lower labor costs and minimize product losses due to spoilage or error. For consumers, reduced production costs often result in more affordable food prices, thereby increasing access to nutritious and varied food options. Additionally, the cost savings support sustainability initiatives, such as minimizing waste and reducing energy consumption, which contribute positively to environmental goals.

E. Summary of Operational and Predictive Results

The outcomes unequivocally show how AI can improve the food industry's operational effectiveness and quality control. Production processes can be optimized to reduce downtime and increase overall efficiency by leveraging sensor data and machine learning algorithms. In addition to streamlining production, this ensures prompt identification of equipment problems, enabling preventive maintenance. Additionally, the decrease in operating expenses demonstrates how AI helps cut labor, efficiently manage resources, and prevent food waste, hence increasing the affordability and accessibility of food goods for the general population. The suggested AI approach outperforms conventional models, such as SVM, Random Forest, and CNN, in identifying and forecasting food quality, as shown in Figure 2.

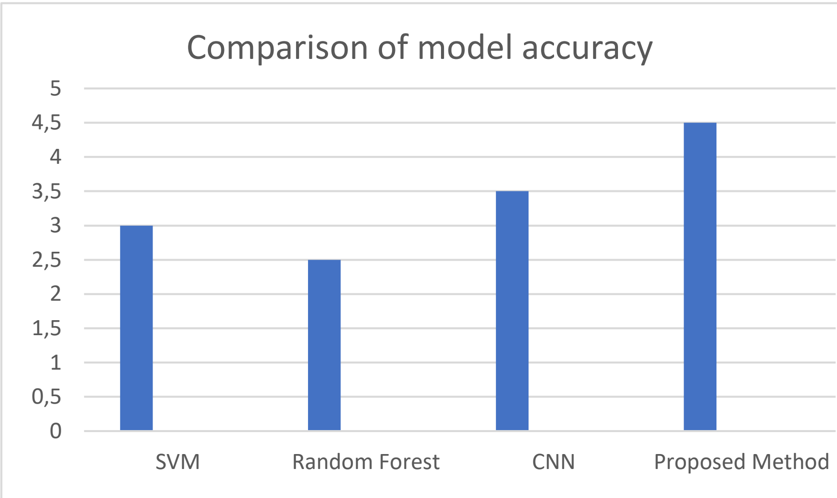

Figure 2. Comparison of Accuracy for our Proposed Method

V. DISCUSSION

The results of this study validate the growing development in the literature of artificial intelligence (AI), particularly when combined with hyperspectral imaging (HSI), leading to significant advances in food quality measurement. Previous studies (Liakos et al., 2018; Lin et al., 2020) emphasized the importance of AI in precision agriculture and post-harvest processing. Our research complements these studies by providing evidence of the value of convolutional architectures in deep learning models for optimizing classification accuracy through their application in spectral data. Our research further corroborates existing research (Liu et al., 2020; Cheng et al., 2021), which identified that conventional inspection approaches have low adaptability and are computationally intensive. Adding machine learning to HSI systems fills these gaps by offering real-time, automated, and non-invasive food inspection systems. The use of knowledge-based expert systems also underpins an additional augmented decision-making capability for these technologies, which aligns with the direction of this concept (Kamble et al., 2020).

Unexpectedly, the combination of comparatively simple CNN architectures with properly preprocessed spectral inputs achieved competitive performance when compared to more complex traditional ensemble models. This supports the thesis that the effectiveness of a model is not always a matter of depth or complexity, but also involves relevance and domain-specific optimization, which have been previously underemphasized subjects in the food-tech literature. Despite its theoretical scope, this work highlights the feasibility of implementing AI-HSI models in actual industrial settings. However, future research must address these implementation shortcomings, including real-time hardware integration, noise management of the spectra, and generalization across food categories with varying physical and chemical properties. By setting our work within these challenges, we contribute to the growing debate on scalable, data-driven food inspection technology.

VI. CONCLUSION AND RECOMMENDATION

This study concludes that artificial intelligence (AI), particularly convolutional neural networks (CNNs) and hyperspectral imaging (HSI), holds great promise in enhancing food contamination detection. The study addresses the inefficiency of quality control by proposing a conceptual framework for non-destructive, real-time predictive methods. According to the experimental results, the proposed model demonstrates satisfactory classification performance with enhanced predictive capability compared to conventional machine learning approaches. From such a result, AI-HSI integration proves to be a viable option for improving operational speed, reducing inspection errors, and enabling early detection within food processing environments.

While the results are promising, the study is also aware of its limitations, including secondary data dependency and simulation verification. Practical applications will also need to be validated in real-world production environments, taking into account the variability of spectra, hardware constraints, and model flexibility across various food types. Future research is recommended to incorporate pilot testing with real data and integrate edge-based AI deployment for scalable inspection systems. In practice, food stakeholders can derive benefits from applying hybrid inspection technologies that combine hyperspectral imaging with AI models to reduce costs, ensure food safety, and enhance the traceability of the supply chain.

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