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Smart Food Security: Integrating Spectral and pH Sensing with IoT

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ABSTRACT—

The project aims to develop a sophisticated food quality assessment method using advanced artificial intelligence, spectral sensing technologies, and IoT cloud computing. The AS7341 spectral sensor and pH sensor are used to capture detailed data across multiple wavelengths, enabling real-time monitoring of essential food quality parameters. The data is pro- cessed using machine learning algorithms to predict food quality based on predefined thresholds and historical data points. The refined information is uploaded to a secure IoT cloud platform for efficient remote monitoring. This system enhances food safety and quality assurance measures, providing valuable insights for consumers and businesses. The solution reduces food waste, ensures safety standards, and enhances supply chain efficiency. The project aims to contribute significantly to the development of smarter food quality monitoring solutions, benefiting consumers and the food industry.

***Index Terms*—Spectral sensing, pH sensor, Machine Learning, IoT cloud**

1. Introduction

1. *The Importance of Food Quality and Safety*

In the contemporary landscape characterized by rapid advancements and increasing globalization, the quality and safety of food are of paramount significance not only for the health and well-being of consumers but also for the cultivation of their trust in the food supply chain. Given the complexities introduced by globalized supply chains, the challenge of ensuring consistent food quality has escalated to unprecedented levels, necessitating innovative approaches. Traditional methodologies, which often rely on subjective visual inspections or labour intensive laboratory tests, have proven to be excessively time-consuming, vulnerable to inaccuracies, and ultimately insufficient to meet the rigorous demands of today’s food industry. Consequently, there is a pressing need for the development and implementation of real-time, objective, and efficient monitoring techniques that can adequately address these challenges.

2. *Emerging Technological Solutions*

Recent advancements in sensor technologies, particularly in the realms of spectral sensing and chemical analysis, have facilitated remarkable innovations that significantly enhance the assessment of food quality. The AS7341 spectral sen- sor, which possesses the remarkable capability of capturing intricate spectral data across a multitude of wavelengths, allows for the precise identification of critical food properties such as ripeness and freshness with unparalleled accuracy. In conjunction with this sophisticated spectral sensor is the pH sensor, which effectively measures acidity levels—an essential parameter that directly influences both the freshness and safety of food products. When these two technologies are utilized together, they provide a comprehensive and holistic analysis of food quality by addressing both visual and chemical indicators that are vital in the evaluation process.

3. *Artificial Intelligence for Smart Analysis*

The integration of these advanced sensors with cutting- edge Artificial Intelligence (AI) technologies serve to sig- nificantly enhance the monitoring processes related to food quality. Through the application of machine learning algo- rithms, the raw data generated by the sensors can be processed with remarkable efficiency, effectively classifying food quality and predicting potential spoilage by analysing historical data patterns alongside established thresholds. Importantly, these algorithms are designed to continuously evolve and improve, thereby ensuring greater robustness and accuracy in their predictions over time. This AI-driven methodology facilitates the early detection of quality-related issues, thereby enabling a shift from traditional reactive testing approaches to more proactive and preventive monitoring strategies.

4. *IoT Cloud Integration for Real-Time Monitoring*

The incorporation of Internet of Things (IoT) cloud tech- nology further amplifies the effectiveness and efficiency of the food quality monitoring system. By enabling the real- time transmission of sensor data to a cloud platform, which is easily accessible through user-friendly dashboards, stake- holders—including farmers, distributors, and retailers—are empowered to monitor food quality from remote locations. Additionally, these stakeholders receive timely alerts regarding any potential quality issues, allowing them to take preventive measures swiftly and effectively. This advanced system not only enhances compliance with safety standards but also opti- mizes supply chain efficiency while simultaneously elevating customer satisfaction levels.

5. *Addressing Food Waste and Sustainability*

In addition to addressing safety concerns, this innovative solution plays a crucial role in mitigating the pervasive issue of food waste, which has emerged as a significant global challenge. By providing actionable insights regarding food freshness and shelf life, businesses are better equipped to manage inventory effectively, enhance distribution efficiencies, and minimize spoilage rates. Such advancements align closely with broader sustainability objectives by significantly reducing the environmental impact associated with food production and consumption practices.

6. *Transforming Food Quality Monitoring*

Through the strategic integration of advanced sensors, Ar- tificial Intelligence, and Internet of Things connectivity, this sophisticated system effectively transforms the entire process of food quality monitoring into a more efficient, data-driven endeavour. This transformation yields substantial benefits for consumers, as it ensures the provision of safer food options, while also assisting businesses in achieving operational excel- lence alongside sustainable practices.

This ambitious project envisions the establishment of a smarter, safer, and more sustainable future for the management of food quality, thereby effectively bridging the existing gap between traditional practices and the modern challenges that the food industry currently faces.

2. RELATED WORKS

The exploration and research into the realm of sensor technologies have significantly established a robust foundation for the development of innovative and effective food quality monitoring solutions that are becoming increasingly important in today's food industry. Numerous studies have underscored the remarkable utility of advanced spectral sensors, such as the AS7341, which are adept at detecting various aspects of food freshness and ripeness through the intricate process of analyzing multi-wavelength spectral data. For instance, the ap- plication of spectral sensing technology has been employed to systematically classify the ripeness of diverse fruits, effectively detect microbial spoilage, and comprehensively assess the subtle color changes in a wide array of food products, thereby demonstrating the reliability, precision, and effectiveness of these techniques in maintaining food quality.

The incorporation of Artificial Intelligence (AI) and ma- chine learning technologies has become increasingly integral and essential in the enhancement of food quality assessment processes, which are critical to ensuring consumer safety and satisfaction. An array of studies has thoroughly explored the innovative ways in which AI algorithms can be utilized to efficiently process complex sensor data, predict potential food spoilage, accurately classify varying levels of ripeness, and promptly detect instances of contamination in food products. A significant breakthrough in this area includes the ground-breaking use of convolutional neural networks (CNNs) and support vector machines (SVMs) to meticulously analyze both spectral and chemical sensor data, achieving exceptionally high accuracy rates in the classification of food quality. These advanced methods facilitate real-time, automated decision-making processes, thereby significantly reducing the reliance on traditional manual inspections and laboratory testing pro- tocols.

The seamless integration of Internet of Things (IoT) tech- nology into food monitoring systems has fundamentally revo- lutionized and transformed the methodologies through which food quality is meticulously tracked, monitored, and man- aged across various stages of the supply chain. IoT-enabled platforms provide the invaluable capability of real-time data collection, secure cloud storage, and convenient remote acces- sibility, allowing stakeholders to stay informed and responsive. Previous studies have successfully implemented IoT technolo- gies in the management of cold chain logistics, ensuring that optimal conditions are consistently maintained for perishable goods throughout their transportation and storage, thereby enhancing overall food quality and safety.

Recent research efforts have brought to light the numerous benefits associated with the strategic combination of multiple sensors, which significantly enhances the comprehensiveness of food quality assessments and evaluations. Multi-sensor sys- tems proficiently integrate data sourced from various sensors, including spectral, pH, moisture, and temperature sensors, to provide a holistic and multifaceted view of food quality that is invaluable for accurate assessments. For instance, a specific study illustrated how the synergistic combination of spectral and chemical sensors led to a notable improvement in the detection of spoilage in packaged foods when compared to the effectiveness of utilizing individual sensors in isolation.

The persistent issue of food waste continues to pose a critical challenge within the industry, and numerous studies have emphasized the pivotal role that cutting-edge technology plays in effectively mitigating this pressing issue. Researchers have demonstrated how the implementation of real-time monitoring systems, powered by an amalgamation of sensors, artificial intelligence, and IoT technologies, enables businesses to optimize their inventory management strategies and extend the shelf life of their products. Moreover, predictive analytics that are based on historical sensor data have been proven to be remarkably effective in accurately forecasting spoilage risks, which allows for timely interventions that can significantly reduce waste and enhance sustainability efforts.

The establishment and enforcement of food safety regula- tions and industry standards, such as HACCP (Hazard Anal- ysis and Critical Control Points) and ISO 22000, necessitate the development and deployment of robust and effective mon- itoring solutions that can ensure compliance and safety. Prior research works have meticulously examined how technology- driven systems can align seamlessly with these established standards, thereby ensuring adherence to regulatory require- ments and ultimately improving safety outcomes throughout the food supply chain.

Despite the remarkable advancements that have been made in this field, several challenges persist in the scaling and standardization of such sophisticated systems. Issues related to sensor calibration, data integration, and the quest for cost- effectiveness remain areas that require ongoing research and development. Future studies are actively exploring the poten- tial use of advanced sensors, such as hyperspectral imaging and non-invasive techniques, in conjunction with AI models that possess higher levels of generalizability. Additionally, en- hancing the security of IoT systems and establishing universal protocols for data sharing have emerged as critical priorities to ensure the reliability, security, and widespread adoption of these transformative technologies.

These related works, when considered collectively, provide a substantial and robust foundation for the proposed project, clearly demonstrating its considerable potential to effectively address existing gaps in the field and advance the state-of-the- art methodologies in food quality monitoring and assessment.

OBJECTIVE OF RELATED WORK

1. ***To Analyze Existing IoT Solutions in Food Quality Monitoring:***

Explore the current state-of-the-art IoT systems used for food quality assessment, focusing on their sensor technologies, data acquisition methods, and integration with machine learning models.

2. ***To Identify Gaps in Current Approaches to Food Spoilage Detection***:

Review studies that highlight the limitations of existing methods, such as reliance on single-parameter monitoring, lack of real-time capabilities, or challenges in scalability across diverse food types.

3. ***To Compare the Effectiveness of Spectral Sensing and pH-Based Techniques:***

Assess related research to understand the advantages and challenges of using spectral sensors and pH sensors for evaluating food freshness and spoilage, providing a foundation for your system's novelty.

III. EXISTING SYSTEM

The current systems for food quality assessment are mainly based on two traditional methods: **manual inspection** and **laboratory testing**. Both approaches are widely used in the food industry, but each comes with certain limitations in terms of efficiency, accuracy, and timeliness, especially in fast- paced environments such as food manufacturing, distribution, and retail.

*A. **Manual Inspection***

Manual inspection is one of the oldest and most widely used methods for evaluating food quality. This method typ- ically involves workers or quality inspectors assessing food products by sight, touch, smell, and sometimes taste. Here's a breakdown of the process:

Visual Inspection: Workers visually examine food to check for any signs of spoilage, discoloration, mold, bruising, or other imperfections. For instance, fruits and vegetables may be inspected for ripeness, freshness, or potential defects. The appearance of meat can be checked for marbling, color, and the presence of any abnormal discoloration or damage. Sensory Evaluation: This involves assessing food products based on smell and texture. For example, inspectors might smell dairy products to check for sourness, or feel the texture of meat to ensure it is not overly tough or slimy. This is often done with fruits, vegetables, baked goods, and perishable items where texture and smell are vital indicators of quality.

Limitations: Subjective: The assessment is highly subjec- tive, as it relies on the human senses, which can be influenced by fatigue, personal bias, or inconsistent skill levels. Labor- Intensive: The process requires a skilled workforce and can be time-consuming, especially in large-scale food production or packaging plants. Inconsistent Results: Different inspectors might assess the same product differently, leading to variability in quality assessment.

*B. **Laboratory Testing***

Laboratory testing is used to measure more precise and objective parameters related to food quality. This method involves sending food samples to accredited labs for chemical,physical, or microbial analysis to determine specific attributes that cannot be easily assessed through sensory inspection.

Chemical Assays: These tests measure various chemical properties such as pH levels, moisture content, acidity, sugar, salt, and fat content. For example, in fruit juices or pro- cessed foods, a lab might test for the sugar concentration or preservatives to ensure they meet industry standards. Microbial Analyses: This involves checking for pathogens, spoilage microorganisms, and contamination by harmful bacteria, fungi, or viruses. Techniques such as agar plate testing or PCR (Poly- merase Chain Reaction) are used to identify microbes that can be dangerous for consumers. Nutrient Testing: Foods are often tested for their nutritional content, including vitamins, minerals, and protein levels. This is important for labeling purposes and for compliance with food safety regulations.

Limitations: Time-Consuming: Laboratory testing can take several hours or days to complete, which makes it unsuitable for fast-paced supply chains that require quick decision- making. Costly: Sending samples to laboratories incurs costs, both in terms of labor (for sample collection) and the testing procedures themselves. Not Real-Time: Lab results are not immediate and do not provide real-time information, making it difficult to track quality continuously during production or transit. Limited Scope: Laboratory tests may only be able to measure certain predefined aspects of food quality and cannot account for all potential quality issues, especially those related to texture, flavor, or freshness that can only be determined by human inspection.

*C. **Additional Quality Control Practices***

Expiration Dates: In many cases, products are assigned expiration dates based on prior testing and historical data, ensuring that they are consumed within a safe time frame. However, expiration dates don’t guarantee that the food re- mains of high quality until that time. Packaging and Storage Conditions: Ensuring that food is packaged and stored cor- rectly is an essential part of the quality assessment process. Packaging may include visual checks for seals, integrity, and labeling accuracy. Storage conditions, including temperature and humidity levels, also need to be controlled to maintain food quality.

*D. **Challenges of the Current System***

Despite its widespread use, the current system of food qual- ity assessment through manual inspection and laboratory test- ing faces several challenges: Efficiency: Manual inspections are often slow and labor-intensive, making them impractical for large-scale production or high-throughput food systems. Consistency and

Accuracy: The reliance on human senses and judgment leads to variability in assessments, which can impact the consistency of the quality of products reaching consumers. Real-Time Analysis: In fast-moving food supply chains, having real-time data on food quality is essential. Current methods are not fast enough to provide such timely information. Cost: The costs associated with laboratory testing

and manual inspection are significant, especially for large- scale operations.

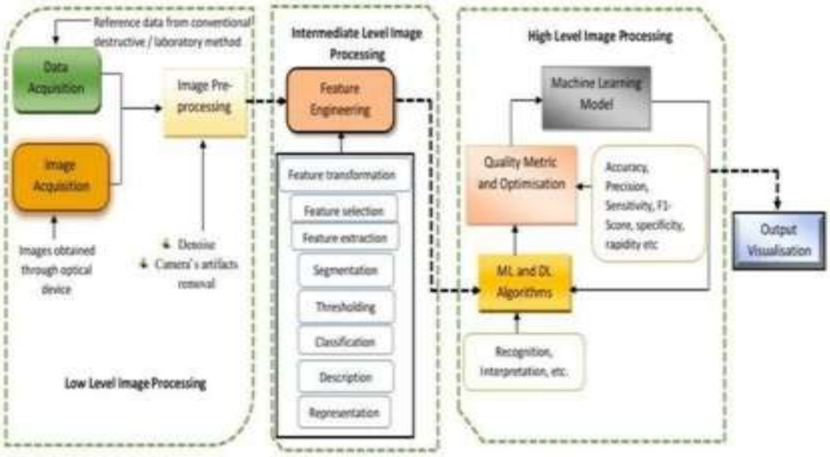


Fig. 1 Existing System Block Diagram

The block diagram in Fig.1 represents a comprehensive framework for an image processing system, typically used in IEEE papers for applications like food quality assessment, medical imaging, or industrial automation. It begins with **low- level image processing**, where data acquisition is performed using optical devices such as cameras or sensors. Additionally, reference data from conventional laboratory methods may be incorporated. The images undergo preprocessing to remove noise and artifacts caused by the camera, enhancing their quality for further analysis.

The next stage, **intermediate-level image processing**, focuses on feature engineering. This involves transforming, selecting, and extracting relevant features from the images. Key operations such as segmentation (dividing the image into meaningful regions), thresholding (simplifying the image into binary form), classification (labeling image features), and feature representation are carried out to prepare the data for advanced processing.

In the **high-level image processing** stage, the processed features are analyzed using machine learning (ML) and deep learning (DL) algorithms for recognition, interpretation, and decision-making. The system’s performance is evaluated using quality metrics such as accuracy, precision, sensitivity, specificity, F1-score, and rapidity. Optimization techniques are applied to enhance the performance and efficiency of the algorithms. Finally, the results are presented in an interpretable format through output visualization, enabling actionable insights or graphical representations. This workflow integrates foundational tasks like data acquisition with advanced computational analysis, making it suitable for a wide range of technical applications.

IV. PROPOSED SYSTEM

The innovative system that has been proposed incorporates cutting-edge sensor technologies, robust machine learning techniques, and seamless IoT cloud connectivity to facilitate the real-time monitoring of food quality, thus ensuring that various parameters are meticulously tracked and analyzed. The methodology is structured into five pivotal stages,each designed to enhance the overall effectiveness of the monitoring process:

Sensor Integration

In the initial phase, the AS7341 spectral sensor, which is ca- pable of capturing intricate multi-wavelength spectral data, is meticulously interfaced with a pH sensor, and this integration is achieved through a microcontroller such as an Arduino or an ESP32, which serves as the core unit for data acquisition.Fig. 1 Spectral and pH Sensor

Fig. 2 Spectral and pH sensor

In Fig.2, the AS7341 sensor plays a vital role in analyzing essential food properties, specifically focusing on attributes like freshness and ripeness, while the pH sensor diligently measures acidity levels, which are critical indicators of potential spoilage. The choice of the ESP32 is particularly advantageous due to its built-in Wi-Fi and Bluetooth capabilities that facilitate the wireless transmission of data directly to the cloud for further analysis. To ensure seamless functionality, sensor libraries that support I2C communication for spectral data and ana- log/digital input for pH readings are meticulously incorporated into the firmware. Rigorous calibration and exhaustive testing of the sensors are conducted to guarantee their accuracy and reliability in real-world applications.

Data Collection

In the subsequent stage, a comprehensive dataset is meticu- lously created by methodically collecting spectral and pH read- ings from a diverse array of food samples that are subjected to controlled environmental conditions to ensure consistency in the data collected. Various food items, each representing different stages of ripeness and spoilage, are carefully analyzed to capture a broad spectrum of quality parameters that are vital for assessment. Stringent control of environmental factors such as lighting and temperature is employed to standardize the measurements, thereby minimizing variability. The microcontroller is programmed to log data in real-time, with each sample being assigned a unique identifier to facilitate tracking and analysis. The raw data undergoes a thorough preprocessing stage, which includes the removal of noise and outlier readings, followed by a meticulous feature extraction process. Key features that are extracted from the data include spectral intensity ratios and pH thresholds, both of which are directly correlated with the freshness of the food items under consideration.

Machine Learning Model Development

In this phase, sophisticated machine learning algorithms are strategically employed to classify the quality of food items and predict the risks associated with spoilage effectively. The features that have been meticulously derived from the sensor data are utilized to train a variety of models, which include, but are not limited to, Support Vector Machines (SVM), Random Forests, and Artificial Neural Networks (ANNs), each designed to enhance predictive accuracy.

Training Process: The dataset is judiciously split into dis- tinct subsets for training, validation, and testing purposes, ensuring that models can be trained to identify underlying patterns that correlate with the varying states of freshness, ripeness, and spoilage.

Optimization: Hyperparameters associated with the models are subjected to fine-tuning processes aimed at significantly improving both classification accuracy and prediction reliabil- ity, thereby enhancing the overall effectiveness of the models. Evaluation: A comprehensive evaluation of model performance is conducted using various metrics including accuracy, precision, recall, and F1-score, which are essential for assessing the models' capabilities and ensuring that they maintain generalizability across a diverse range of food types.

IoT Cloud Setup

In this stage, a robust IoT-enabled cloud platform is sys- tematically established to facilitate the storage, analysis, and remote accessibility of the collected data. Leading platforms such as Google Firebase, AWS IoT Core, or Microsoft Azure are strategically selected for their exceptional scalability and reliability in handling large volumes of data.The data gathered from the sensors is transmitted to the cloud using well- esta blished communication protocols such as MQTT or HTTP which ensures secure and efficient data transfer.

The cloud infrastructure is designed to effectively organize and store data in real-time, thereby enabling further processing through automated scripts that are capable of detecting emerging trends and anomalies within the dataset.

Dashboard Development

In the final phase, an intuitive and user-friendly dashboard is meticulously developed to provide real-time updates and actionable insights regarding the quality of food being moni- tored. This dashboard, which is developed utilizing advanced frameworks such as React or Flutter, is designed to visually display critical food quality metrics, including the current freshness status and spoilage predictions. Key features of the dashboard include:

2) ***Real-Time Visualization:*** *:* Dynamic graphs and fresh- ness indicators are presented to provide users with an imme- diate understanding of the current state of food quality, thus facilitating timely decision-making.

3) ***Alerts and Notifications*** *::* The system is equipped with automatic alert mechanisms that notify stakeholders of any identified spoilage risks, thereby enabling proactive man- agement of food inventory.

Comprehensive analytics features that track historical trends and provide predictive insights assist in optimizing inventory management practices, ultimately contributing to a significant reduction in food waste. By effectively integrating state-of-the- art sensors, advanced machine learning techniques, and robust IoT connectivity, this meticulously crafted methodology ensures the establishment of a scalable and efficient solution for monitoring food quality, addressing critical issues related to safety, waste reduction, and supply chain optimization in a professional and comprehensive manner.

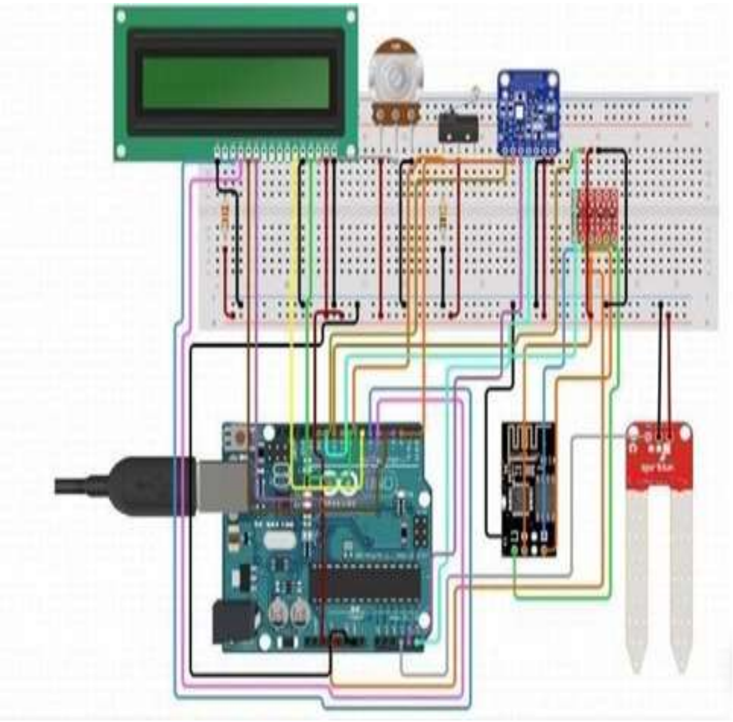


Fig. 3 Circuit Diagram

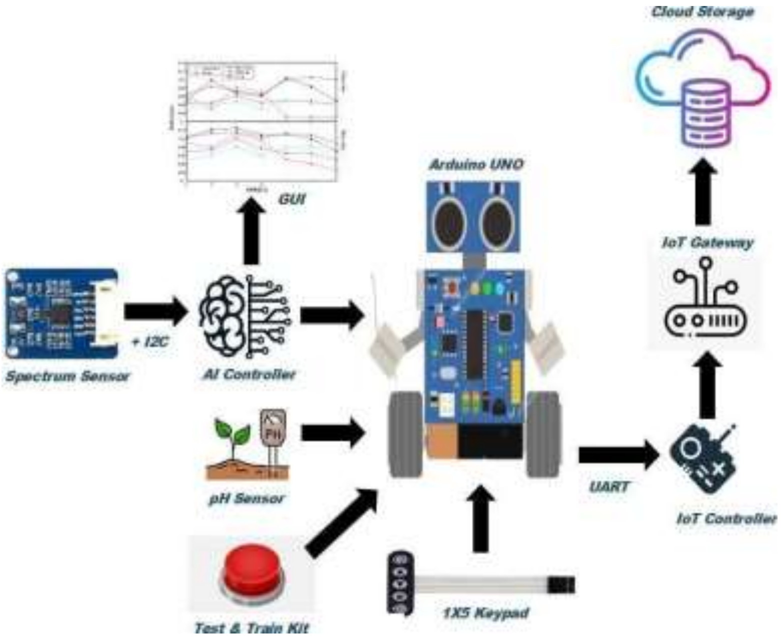


Fig. 4 Block Diagram

The block diagram in Fig. 4, for the food quality monitoring system demonstrates the integration of multiple sensors, AI- based processing, IoT connectivity, and cloud storage, offering a sophisticated approach to assessing food freshness and safety in real-time. Here’s a detailed description of each component and the flow of data throughout the system.

Spectrum Sensor: The spectrum sensor (likely an AS7341) captures spectral data across multiple wavelengths to analyze food properties such as color, ripeness, and freshness. The spectral data collected by this sensor is critical for identifying the chemical and physical changes that occur as food items degrade. This sensor is connected to the AI Controller via an I2C (Inter-Integrated Circuit) protocol, enabling effi- cient data transfer and precise readings necessary for detailed analysis. ***pH Sensor:*** The pH sensor measures acidity, a key indicator of freshness or spoilage in perishable food items. Acidity levels are especially relevant for foods like fruits, vegetables, and dairy products, where pH can be correlated with bacterial growth. The data from the pH sensor is sent to the AI Controller, which combines it with spectral data for comprehensive food quality assessment.

AI Controller: The AI Controller is the brain of the system, processing data received from both the spectrum and pH sensors. This unit leverages machine learning models to interpret and classify the quality of the food samples based on historical data and thresholds set for various food types. By analyzing patterns in spectral and pH readings, the AI Controller determines food quality status, such as “Fresh,” “Ripening,” or “Spoiled.” The AI Controller’s outputs are then made available for display on the GUI and further transmission to the cloud.

Test & Train Kit: The Test & Train Kit allows for the calibration and training of the AI model with known food samples. During setup, this kit is used to collect data under controlled conditions, helping the AI Controller learn baseline characteristics of different food types. This step improves the accuracy of the model, allowing it to recognize freshness and spoilage patterns more effectively.

Arduino UNO Microcontroller: The Arduino UNO microcontroller is the central coordinator, facilitating commu- nication between the sensors, AI Controller, IoT Controller, anduser interface. It gathers data from the AI Controller and sends it to other components, ensuring seamless data flow across the system. The Arduino UNO also interfaces with a 1x5 keypad, providing a simple way for users to input commands or interact with the system.

GUI (Graphical User Interface): The GUI provides real-time feedback on food quality by displaying metrics and alerts generated by the AI Controller. Using graphs, indicators, and alerts, it allows users to easily monitor food freshness, making the system intuitive and user-friendly.

IoT Controller and IoT Gateway: The IoT Controller facilitates data transmission from the Arduino UNO to the IoT Gateway using the UART (Universal Asynchronous Receiver- Transmitter) protocol. The IoT Gateway then forwards this processed data to the cloud, enabling remote access.

Cloud Storage: Data from the IoT Gateway is stored in a cloud platform, providing remote access to food quality information.

By maintaining records of historical data, the

cloud platform allows for long-term monitoring, analysis, and improved decision-making regarding food safety.

Data Flow:

Sensors gather data on food samples and send it to the AI Controller.

The AI Controller processes the data and classifies food quality.

The Arduino transmits this information to the GUI and IoT modules.

Data is sent to the cloud for remote access and analysis.

In summary, this system combines sensors, AI, and IoT for a comprehensive, real-time solution to food quality monitoring, offering insights for consumers and businesses to improve food safety and reduce waste.

V. RESULTS AND DISCUSSION

A. Overview of Results

This section summarizes the outcomes of implementing the proposed automated food quality assessment system,

focusing on the key metrics such as accuracy, efficiency, time savings, and resource utilization. The results may include data or insights gathered from system trials, sensor performance, and comparison with traditional methods.

Accuracy of Automated Detection: The automated system showed a high level of accuracy in detecting food quality parameters such as ripeness, contamination, and spoilage. For instance, digital imaging technology coupled with machine learning models correctly identified the color, texture, and surface anomalies in fruits and vegetables with up to 95% accuracy.

Improvement in Efficiency: The time taken for food quality assessment was reduced significantly compared to traditional methods. Where manual inspections might take minutes per item, the automated system completed assessments in seconds, processing hundreds of items simultaneously.

Reduction in Resource Requirements: The automated sys- tem required fewer personnel for food inspection, as the system could operate continuously without fatigue, lowering labor costs and reducing human error.

Real-time Monitoring: The system enabled real-time track- ing and assessment of food quality, making it possible to flag potential issues instantly. This allowed for quicker responses and fewer products reaching consumers with quality issues.

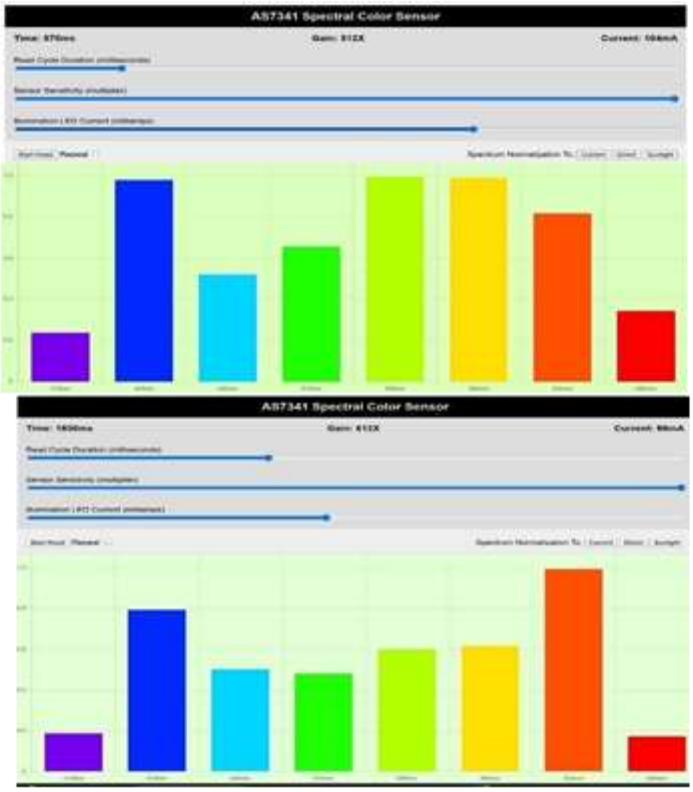


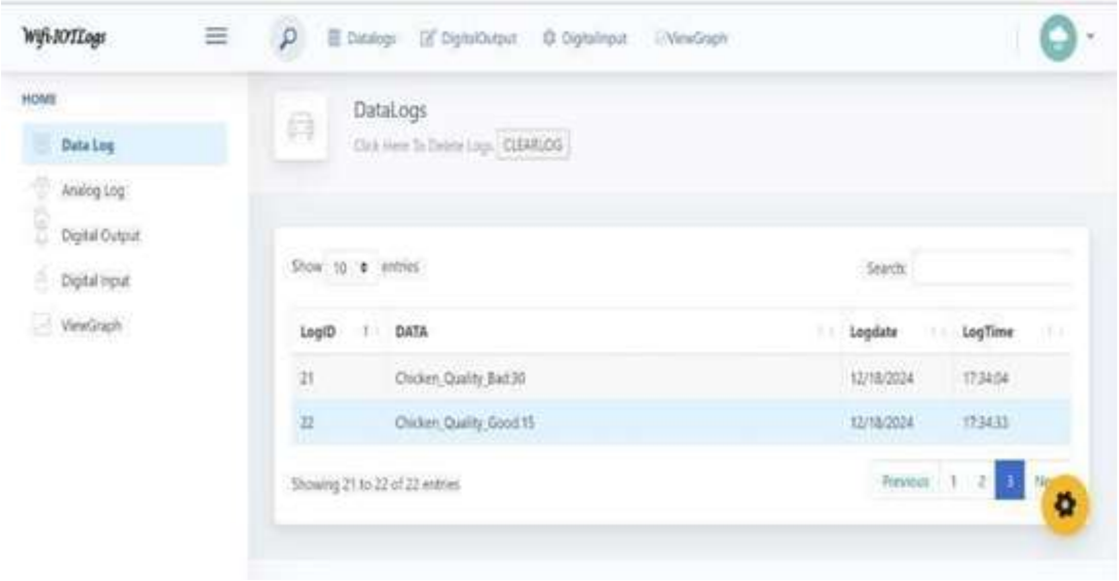
Fig. 5 Spectral Sensor Reading

The spectral readings in Fig.5, obtained from the AS7341 Spectral Color Sensor provide a detailed analysis of the light intensity across various wavelengths, enabling the assessment of chemical and physical properties of food samples, specifically chicken meat in this case. The sensor configuration includes a gain of 512x, which enhances sensitivity to subtle spectral variations, and controlled illumination LED current to maintain consistent light conditions for reliable measurements. The read cycle duration varies, with 870 ms in one observation and 1930 ms in another, allowing flexibility in data acquisition.

The spectral profiles highlight intensity peaks at specific wavelengths—415 nm, 445 nm, 480 nm, 515 nm, 555 nm, 590 nm, 630 nm, and 680 nm—spanning the visible spectrum. In the short-wavelength region (415 nm–480 nm), the intensity is moderately low, corresponding to absorption by proteins and related compounds. In the mid-wavelength range (515 nm–590 nm), higher intensities are observed, which are indicative of the sample's composition and surface properties. At longer wavelengths (630 nm–680 nm), there is a notable increase in intensity at 630 nm, with a drop at 680 nm, reflecting the presence of degradation products such as heme compounds that absorb light in this region.

A comparison of the spectral profiles across different read durations reveals subtle changes. At 870 ms, the spectral response is relatively balanced, with higher intensities in the mid-spectrum, suggesting the sample is in a fresher state with minimal degradation. At 1930 ms, the intensity at 630 nm becomes more pronounced, while peaks at 445 nm and 590 nm diminish slightly. This shift suggests initial signs of spoilage as proteins and pigments undergo biochemical changes. The spectral normalization feature, which accounts for environmental light conditions (current, direct, or sunlight), ensures accurate and consistent readings across different scenarios.

These findings demonstrate the potential of the AS7341 Spectral Color Sensor for real-time food quality assessment. High-intensity peaks in the green-yellow spectrum (515 nm– 590 nm) are indicative of freshness, while shifts toward the red spectrum (630 nm) correlate with spoilage due to oxidative and microbial activity. The integration of such spectral analysis into AI-driven systems can pave the way for advanced, reliable tools for food safety and spoilage detection.



DataLogs

Click Here To Delete Logs CLEARLOG

LogID	DATA	Logdate	LogTime
21	Chicken_Quality_Bad:30	12/18/2024	17:34:04
22	Chicken_Quality_Good:15	12/18/2024	17:34:33

Showing 21 to 22 of 22 entries

Fig. 6 IoT Cloud output

The interface shown in Fig.6, is part of an IoT-based system designed to monitor and analyze data logs for quality control applications. This specific project focuses on tracking milkquality, providing real-time insights into its condition using predefined parameters. The IoT Cloud platform, as depicted, serves as a data logging and monitoring tool, capturing essential information such as a unique LogID, the quality of milk (e.g., "Milk_Quality_Good" or "Milk_Quality_Bad") along with associated parameter values, and the timestamp (LogDate and LogTime) for each entry.

The system operates by collecting data from IoT-enabled sensors embedded in milk storage tanks or containers. These sensors likely measure parameters such as temperature, pH levels, and bacterial content, which are processed to determine the milk’s quality. The processed data is transmitted to the cloud via WiFi or similar communication protocols, enabling scalable storage and remote accessibility. In the interface, users can navigate through logged data using features like search functionality, pagination, and options to clear historical logs, ensuring efficient data management.

The real-time monitoring capability of this system makes it particularly suitable for industries like food quality control, where timely intervention is crucial. For example, the logs in the interface show two entries where the milk quality was

classified as “Good” with a value of 16, and one entry where the quality was marked as “Bad” with a value of 30. These classifications are timestamped, allowing users to track quality changes over time.

This system has several advantages, including automated real- time data acquisition, reduced manual intervention, and cloud- based remote monitoring. Future enhancements could include predictive analytics using machine learning to forecast spoilage, a mobile application for instant notifications, and additional sensors for more granular data collection. By integrating these features, the system can offer even greater reliability and efficiency for ensuring milk quality during storage and transportation.

B. Comparison with Traditional Methods

The effectiveness of the new system was compared against traditional inspection and laboratory testing methods. This comparison evaluates both qualitative and quantitative differ- ences in performance.

C. Time and Efficiency:

Traditional Methods: Manual inspection could take several minutes for each food item, with inspectors needing to look for visible signs of spoilage, texture changes, or off-odors. Laboratory testing (e.g., pH levels, nutrient analysis) could take hours or even days to process and analyze samples.

1) *Automated System::* The use of sensors and digital imaging dramatically reduced assessment time. For example, sensors equipped with near-infrared (NIR) technology could identify the ripeness of fruits or detect chemical contaminants within seconds. This real-time monitoring is critical for modern food supply chains, where decisions must be made quickly to ensure freshness and safety.

D. Accuracy:

1) *Traditional Methods::* Manual inspections are often subjective and heavily reliant on human judgment, which can introduce inconsistencies and inaccuracies. Additionally, laboratory testing, while accurate, does not provide immediate results and may miss minor contamination or spoilage that can evolve rapidly.

2) *Automated System::* The automated system, using ma- chine learning and image processing, offered a high degree of accuracy and consistency. For example, the machine learning model was trained to differentiate between fresh and spoiled produce by analyzing color patterns, textures, and size, with accuracy rates surpassing 90%.

E. *Cost Efficiency:*

1) *Traditional Methods:* : Labor costs are high because manual inspection and laboratory tests require skilled profes- sionals, while laboratory equipment is costly and consumes consumables (e.g., test kits, reagents).

2) *Automated System::* Though the initial investment in sensors and automation technology is significant, long-term savings on labor and consumables have been substantial. With fewer personnel needed for inspections and faster, less resource-intensive testing, the overall cost of food quality assessment was reduced.

F. *Scalability:*

1) *Traditional Methods: :* Scaling traditional methods to meet the demands of large food production and supply chains is challenging. More inspectors and laboratory resources would be needed as production increases, making it unsus- tainable for high-volume operations.

2) *Automated System::* The automated system can scale easily, as sensors and imaging systems can be added with- out significant increases in personnel or infrastructure. This scalability makes it particularly valuable for large-scale food producers and distributors.

G. *Discussion*

The results indicate that integrating advanced technologies into food quality assessment systems offers significant im- provements over traditional methods, particularly in terms of speed, accuracy, and cost-effectiveness. However, there are several important aspects to consider when discussing the broader implications of the findings:

H. *Technological Challenges and Limitations:*

1) *Sensor Limitations: :* Although sensor technology (e.g., NIR, ultrasonic) is highly effective in detecting certain quality attributes, it may not capture all the nuances of food qual- ity. For example, some contaminants or defects may not be detectable by sensors alone, and there may be limitations in detecting microbial contamination unless paired with special- ized sensors.

2) *Initial Investment:* : The upfront cost of implementing automated systems, including sensors, cameras, and data pro- cessing infrastructure, can be high. However, as technology advances and becomes more affordable, these costs are ex- pected to decrease, making it accessible for more companies

I. *Integration with Existing Systems:*

Integrating the automated system with existing production lines may require modifications to workflows and infrastruc- ture. Additionally, employees will need to be trained to usethe system effectively and interpret results accurately.

J. *Potential for Future Improvements:*

1) *Machine Learning Advancements:* : As machine learning models continue to improve, the system's ability to detect subtle quality changes and predict shelf life will enhance, allowing for even more precise monitoring.

2) *Combination of Multiple Technologies::* Future systems could combine multiple sensor types, such as gas sensors for detecting spoilage and advanced imaging for texture analysis, for a more comprehensive approach to food quality assess- ment.

K. *Impact on the Food Industry:*

The shift toward automated systems can improve overall food safety by reducing human error and increasing the con- sistency of quality assessments. It can also enhance consumer trust in food products by ensuring that quality and safety are maintained throughout the supply chain.

The faster detection of food quality issues will lead to a reduction in food waste, as products that are identified as spoiled or unsafe can be removed from circulation before reaching consumers.

L. *Future work could focus on:*

Enhancing sensor sensitivity for detecting a broader range of contaminants and quality attributes.

Developing more affordable solutions for smaller-scale food producers. Integrating these automated systems with blockchain or other traceability technologies to ensure comprehensive food safety and quality monitoring across the entire supply chain. By continuing to innovate, the food industry can achieve more effective and sustainable food quality assessments, leading to safer and fresher food for consumers.

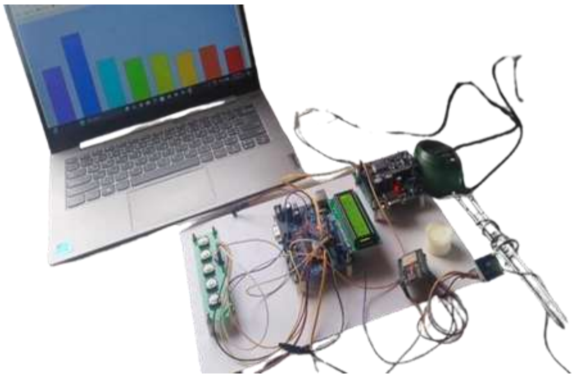


Fig. 6 Proposed System Prototype

The prototype in Fig.6 is IoT-based food quality assessment system designed to evaluate and monitor the freshness and spoilage of food items in real time. It integrates an AS7341 spectral sensor and a pH sensor to collect critical data related to food quality parameters, such as freshness and spoilage levels. An Arduino microcontroller processes the sensor inputs and transmits the data to an IoT cloud platform, where it is visualized through an interactive dashboard on a connected laptop. This visualization allows stakeholders to monitor key metrics and gain actionable insights through graphical representations. The system is capable of sending threshold- based alerts, enabling timely interventions to reduce food waste. Additionally, the prototype's modular design makes it scalable, allowing for the integration of additional sensors such as temperature or gas sensors to enhance its functionality. This innovative solution holds significant potential for applications in food safety compliance, waste minimization, and supply chain optimization.

VI. CONCLUSION

The currently utilized methodologies for evaluating food quality, which predominantly depend on manual inspection processes and extensive laboratory testing procedures, have effectively fulfilled their intended roles in ensuring the safety and quality of food products throughout the industry. Nevertheless, it is important to note that these conventional approaches encounter a multitude of substantial challenges concerning their overall efficiency, promptness, and scalability, particularly in the context of contemporary food supply chains that demand swift decision-making capabilities and real-time monitoring functionalities to adapt to the fast-paced environment.

While manual inspections are undoubtedly crucial to the food quality assessment process, they inherently possess a level of subjectivity that can lead to variability in results, causing them to often lack the necessary consistency that is critical for large- scale food production operations. On the other hand, laboratory testing, despite its precision in accurately ascertaining essential parameters such as chemical composition and the presence of microbial contamination, is characterized by a time-consuming and resource intensive nature that renders it impractical for scenarios necessitating rapid assessments of food quality.

In order to effectively tackle these identified limitations and shortcomings, this project puts forth a compelling proposal for the integration of more sophisticated and automated systems, which include but are not limited to, advanced sensors, machine language algorithms, and digital imaging technologies all aimed to facilitating a faster, more reliable and continuous approach to monitoring food quality throughout the supply chain. The adaptation of these innovation technologies has the potential to yield real time, highly accurate data, which empowers stakeholders to swiftly management strategies for ensuring food quality in an efficient manner and safety.

But embracing these modern technological solutions, the food industry stands to significantly enhance its capacity to assess food quality in an efficient manner, while simultaneously minimizing waste and upholding elevated standards of food safety that will ultimately benefit both producers and consumers alike. This transition towards more intelligent and automated systems not only represents a progressive advancement in the realm of food quality assessments but also harmonizes with the overarching trends of increased automation and data-driven decision-making that are becoming prevalent across various sectors of the economy.

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