

Smart Ethylene Management System: IOT Based Prevention of Premature and Artificial Ripening in Fruits

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Abstract --- Fruit ripening is a critical post-harvest process that directly impacts the quality, market value, and shelf life of fruits. Traditional ripening methods, such as manual application of ethylene gas or chemical agents like calcium carbide, often result in uneven ripening, poor quality, and potential health hazards. Additionally, improper control of environmental parameters such as temperature and humidity leads to over-ripening, spoilage, and economic losses. To address these challenges, the proposed project—Automated Fruit Ripening, Quality Detection, and Sorting System integrates Internet of Things (IoT) and Machine Learning (ML) technologies to create an intelligent, automated solution for fruit ripening management. Using an ESP32 microcontroller with embedded sensors, the system monitors key parameters including ethylene gas concentration, temperature, humidity, color, and weight. The data is processed through a trained ML model to classify the ripening stage as unripe, semi-ripe, ripe, or overripe. The results are displayed on an LCD and transmitted to a cloud platform for remote monitoring via a mobile application. This approach enhances precision, ensures fruit quality, reduces manual labor, and supports sustainable agricultural practices through automation and data-driven decision-making.

Key Words: Internet of Things (IoT) , Machine Learning (ML) ,ESP32 microcontroller , ML model

1. INTRODUCTION

Agriculture remains a cornerstone of economic development, especially in agrarian nations where it contributes significantly to food security, employment, and exports. Among various agricultural commodities, fruits hold substantial importance due to their nutritional value and commercial demand in both domestic and international markets. The ripening of fruits is a complex physiological process involving biochemical and physical transformations such as color change, softening, and sugar accumulation.

These changes are influenced by environmental parameters like temperature, humidity, and ethylene gas concentration. Traditionally, fruit ripening is conducted either naturally or through the manual application of ripening agents. However,

such methods often lack precision and control, leading to uneven ripening, contamination, and increased post-harvest losses. Excessive dependence on manual monitoring not only raises labor costs but also introduces health risks when harmful substances like calcium carbide are used. With advancements in IoT and Artificial Intelligence (AI), it has become possible to modernize traditional agricultural practices. IoT-enabled systems allow real-time monitoring of environmental conditions using embedded sensors and wireless communication technologies, while Machine Learning (ML) models analyze sensor data to predict and classify ripening stages accurately.

The proposed Automated Fruit Ripening, Quality Detection, and Sorting System leverages these technologies to enhance efficiency, ensure uniform fruit quality, and provide remote monitoring capabilities. By minimizing human intervention and optimizing environmental control, this system aims to reduce post-harvest losses, improve product consistency, and promote the goals of sustainable smart farming.

2. LITERATURE SURVEY

A literature review provides a critical analysis of existing work, research trends, and technological developments related to the proposed project. It forms the foundation for understanding current challenges, identifying research gaps, and developing improved systems. In recent years, the integration of IoT (Internet of Things), Artificial Intelligence (AI), and Machine Learning (ML) has revolutionized the agricultural sector. These technologies have enabled precise monitoring, automated control, and data-driven decision-making in farming and post-harvest management. Fruit ripening, being a crucial post-harvest process, directly affects the market value, nutritional quality, and shelf life of fruits.

Conventional ripening methods are often inefficient, unsafe, and non-uniform. To overcome these issues, researchers have developed IoT-enabled and sensor-based smart systems for monitoring ethylene gas levels, temperature, humidity, and other ripening parameters. Some studies have also incorporated machine learning and image processing to assess the quality and ripening stages of fruits. This chapter reviews existing research and technologies relevant to fruit ripening automation, IoT-based monitoring, and ML-based quality detection and sorting system.

Ravindran A., Anitha R., Ajith R. (2015), "A Review on Non-Destructive Techniques for Evaluating Quality of Fruits," IJERT. This research focuses on various non-destructive methods for assessing the internal and external quality of fruits without physically altering or damaging them. The paper discusses techniques such as near-infrared (NIR) spectroscopy, ultrasonic sensing, color and texture analysis, gas chromatography, and computer vision methods. The authors emphasize that these non-invasive techniques are essential for continuous monitoring of fruit quality in industrial processes.

The study concludes that color and gas-based sensors can provide reliable information about the ripeness level, firmness, and sugar content. The paper also highlights the challenges of integrating these sensors into cost-effective embedded systems for real-time applications. This work forms the foundation for understanding the range of sensing technologies applicable to ripening analysis and justifies the adoption of low-cost sensors like MQ135 and TCS3200 in the proposed system.

Srividhya V., Sujatha K., Ponmagal R. S. (2016), "Ethylene Gas Measurement for Ripening of Fruits Using Image Processing," Indian Journal of Science and Technology. This paper presents a hybrid approach combining ethylene gas measurement with imagebased analysis for determining fruit ripeness. The authors utilize an MQ3 gas sensor for ethylene detection and employ digital image processing techniques to analyze color transformations as fruits mature. The study uses Artificial Neural Networks (ANN) to correlate gas concentration and color intensity with ripening stages. The research successfully demonstrates that ethylene concentration increases as fruit color transitions from green to yellow or red, validating the use of gas sensors as reliable indicators of ripening. Moreover, the study emphasizes that fusing sensor and image data improves accuracy compared to using either method individually. This directly supports the concept of multi-sensor fusion adopted in your project, which integrates gas, color, temperature, and weight sensors for precise classification of fruit ripeness.

Zhang X., Li Y., Hong T., Tegeltija S., et al. (2023), "Response Characteristics Study of Ethylene Sensor for Fruit Ripening under Temperature Control," Sensors. This recent paper investigates the performance characteristics of an ethylene sensor under varying temperature conditions to understand its reliability in fruit ripening applications. The authors built a controlled chamber where they monitored ethylene emission, temperature, and humidity, correlating these parameters with fruit firmness and sugar content. The study revealed that temperature significantly influences sensor sensitivity and response time, implying that calibration must account for environmental changes. This finding is critical to your project, as the proposed system uses both an MQ135 gas sensor and a DHT22 temperature sensor. By monitoring temperature and humidity alongside gas concentration, your project ensures more accurate and stable ethylene detection. The paper also validates the use of microcontroller-based compensation algorithms to correct for sensor drift and temperature fluctuations.

Zhao M., You Z., Chen H., Wang X., Ying Y., Wang Y. (2024), "Integrated Fruit Ripeness Assessment System Based

on an Artificial Olfactory Sensor and Deep Learning," Foods Journal. This advanced study introduces an integrated approach combining an artificial olfactory 5 sensor array and deep learning algorithms for non-destructive fruit ripeness evaluation. The system uses volatile organic compound (VOC) sensors that mimic the human sense of smell and a DenseNet-based convolutional neural network to analyze the collected gas patterns. The authors achieved over 97% classification accuracy across multiple fruit types such as mango, peach, and banana. The paper demonstrates how sensor data, when coupled with deep learning, can precisely determine ripeness levels without relying on external imaging systems. Although the system is relatively costly due to specialized gas sensors, the concept of data-driven pattern recognition directly aligns with the ML-based classification in your project. Your project similarly employs supervised learning models (like Decision Tree or Random Forest) trained on multi-sensor data to predict ripeness stages.

Mohan R., Sreekumar K. (2019), "A Literature Review on Machine Vision-Based Approaches for Ripeness Detection of Fruits," International Journal of Computer Applications. This review paper provides an in-depth analysis of vision-based ripeness detection methods that use color, shape, and texture features. It discusses various image segmentation techniques such as RGB color space transformation, thresholding, edge detection, and morphological analysis to extract meaningful parameters from fruit images. The authors compare traditional classifiers like k-Nearest Neighbors (kNN) and Support Vector Machines (SVM) with modern deep learning networks for classification accuracy. The study concludes that while image-based systems can achieve high precision, they are often computationally intensive and unsuitable for embedded platforms with limited resources. Your project addresses this limitation by using compact, low-cost color sensors that capture RGB data without the need for image processing hardware. Thus, it achieves similar outcomes—accurate color-based ripeness detection—while maintaining real-time capability on the ESP32 microcontroller.

Karlapudi S. N., et al. (2025), "Fruit Ripeness Detection Using CNN Model," IJSREM. In this paper, the authors implement a Convolutional Neural Network (CNN) to classify fruit ripeness based on image datasets of apples, bananas, and mangoes. The system preprocesses images to normalize lighting and color variations before feeding them into the CNN model. The network successfully distinguishes between unripe, semi-ripe, ripe, and overripe stages with a high degree of accuracy. The study demonstrates the potential of deep learning for handling non-linear relationships between visual features and ripeness stages. However, the authors acknowledge that deploying such models on low-power microcontrollers poses computational challenges. This limitation supports the rationale for your project's use of lightweight ML algorithms that can be trained on external computers and later embedded in ESP32 firmware for edge processing.

3. METHODOLOGY

The project revolves around an IoT-based system that automates the monitoring and control of environmental factors affecting the ripening process of fruits and vegetables. The

system is built on the ESP32 microcontroller and integrates multiple sensors and actuators to ensure optimal conditions inside the storage container. The working methodology is divided into the following steps:

System Initialization:

The ESP32 microcontroller is initialized to connect with the various sensors: MQ2 gas sensor for ethylene detection, DHT sensor for temperature and humidity, moisture sensor, and weight/load sensor for monitoring fruit conditions.

The LCD display and Blynk IoT platform are set up to receive real-time data, providing both local and remote monitoring.

Data Acquisition:

MQ2 Gas Sensor: The sensor continuously monitors the concentration of ethylene gas emitted by the fruits and vegetables inside the container.

DHT Sensor: This sensor measures the temperature and humidity levels within the container, ensuring that conditions remain optimal for slow ripening.

Moisture Sensor: The moisture content of the fruits is measured to ensure they remain in a dry environment, which helps prevent spoilage and hastens ripening.

Weight/Load Sensor: The load sensor measures the total weight of the stored fruits and vegetables, providing additional insights for tracking.

Condition Monitoring:

The sensor data is continuously processed by the ESP32. The system monitors the environmental conditions and compares them to preset thresholds:

If the temperature, humidity, or moisture levels rise above the optimal thresholds, the system identifies the need for air circulation.

If the ethylene gas concentration increases beyond a safe limit, the system detects it as a sign of faster ripening.

Automated Response:

DC Exhaust Fan Activation:

When the temperature, humidity, or moisture exceed preset limits, the relay module triggers the DC fan, which circulates air within the container to maintain the desired conditions. The fan ensures that fresh air is continuously supplied, preventing the accumulation of gases and excess humidity.

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DC Pump Activation As ethylene gas levels increase, indicating that the fruits are ripening faster, the relay triggers the DC pump to spray an ethylene absorbent over the fruits and vegetables. This slows down the ripening process by reducing the concentration of ethylene in the container.

Data Logging and Remote Monitoring:

All sensor data, including ethylene concentration, temperature, humidity, moisture, and weight, are logged and displayed on the local LCD display.

The ESP32 microcontroller also sends the data to the Blynk IoT platform through the cloud. Users can monitor these parameters remotely through the Blynk app on their smartphones.

In case of any anomalies, such as high ethylene levels or increased temperature, the system sends alerts to the user's phone, allowing them to take action if needed.

User Control and Alerts

The system allows the user to remotely control the fan and pump through the Blynk app. Users can manually trigger these devices or let the system operate automatically based on sensor readings.

Real-time notifications are sent to the user when environmental factors exceed safe limits, providing timely updates for intervention.

System Shutdown

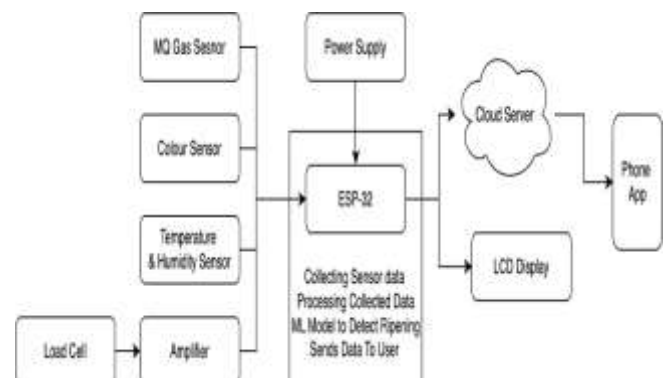
Once the storage conditions are restored to normal levels, the system deactivates the DC fan and DC pump automatically, ensuring energy efficiency and optimal performance.

This methodology ensures an efficient, automated system for controlling the ripening process, reducing post-harvest losses and prolonging the shelf life of fruits and vegetables.

A. Block Diagram:

Fig.3.1 shows the block diagram illustrating the proposed ML model for prevention of premature and artificial fruit ripening.

Fig.3.1: Block diagram illustrating the proposed model .



B. Circuit Diagram:

Fig. 2 shows the complete circuit diagram illustrating the interconnection of all hardware components including ESP32 GPIO pin assignments, MQ2 sensor, DHT22 sensor connections and Wi-Fi connection path to the Blynk cloud.

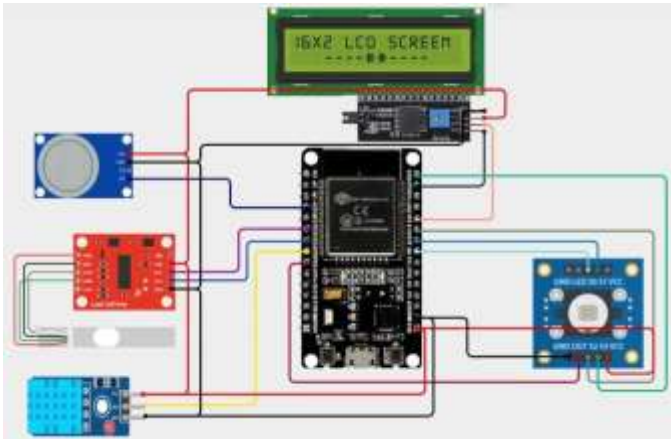


Fig 2. Circuit Diagram -ESP32, MQ2 sensor, DHT22 sensor and LCD

C. System Workflow

The system begins by initializing the ESP32 microcontroller, establishing Wi-Fi connectivity, and activating all integrated sensors. Environmental and physical parameters, including ethylene concentration, fruit colour, temperature, humidity, and weight, are continuously acquired and pre-processed to ensure data reliability. The processed sensor data is then supplied to an embedded machine learning model, which intelligently determines the fruit's ripening stage. The resulting measurements and ripeness classification are displayed locally on the LCD and simultaneously transmitted to the Blynk cloud platform, enabling real-time remote monitoring and data visualization.

4. HARDWARE AND SOFTWARE IMPLEMENTATION

A. Hardware Components

Table 1 lists all hardware components with specifications.

Component	Model	Function
Microcontroller	ESP32	Processing, Wi-Fi, Motor control
Gas Sensor	MQ135	Detects Gas
Colour Sensor	TCS3200/APDS9960	Measure RGB colour

Temp/Humidity sensor	DHT22	Monitors Temperature/humidity
Weight Measurement unit	Load cell + HX711	Measures fruit weight
Display module	16x2 LCD	Display Readings
Communication module	ESP32 built-in Wi-Fi	Uploads real-time data to Blynk cloud
Platform	Breadboard/PCB	Used for hardware integration

Table 1 lists all hardware components with specifications.

GPIO Pin	Connected to	Function
GPIO 34	MQ135 Gas Sensor (Analog Output)	Reads gas concentration values
GPIO 32	HX711 Data (DT)	Receives amplified weight data
GPIO 33	HX711 Clock (SCK)	Provides clock signal for HX711 communication.
GPIO 25	DHT22 Sensor	Reads temperature and humidity data.
GPIO 26	Color Sensor Output	Receives RGB/color
GPIO 21	LCD I ² C SDA	Serial Data Line for LCD communication
3.3V Pin	Sensors & Modules	Supplies regulated 3.3V power.
5V/VIN Pin	MQ135 / LCD / Servo	Supplies regulated 5V power.

C. Software Implementation

The software implementation of the Smart Ethylene Management System is developed using the Arduino IDE with Embedded C/C++ programming. The ESP32 reads data from the sensors, processes it, and controls the exhaust fan and spray pump based on predefined conditions. Using its built-in Wi-Fi, the ESP32 sends real-time sensor data to the Blynk IoT Platform, where users can monitor environmental conditions and receive alerts remotely. This enables automatic control and continuous monitoring of the fruit storage environment.

5. RESULTS AND DISCUSSION

A. Experimental setup

The experimental setup consisted of an ESP32 microcontroller connected to an MQ135 gas sensor, TCS3200 color sensor, DHT11 temperature and humidity sensor, and a load cell for weight measurement. Fresh fruit samples were placed in a controlled environment, where the sensors continuously monitored ethylene gas concentration, fruit color, temperature, humidity, and weight during the ripening process. The collected data was processed by the ESP32 and transmitted to the Blynk IoT platform via Wi-Fi for real-time monitoring, analysis, and classification of fruit ripeness.

B. System Performace Summary

Table 3 summarizes overall system performance .

Ripeness Stage	Expected (Actual Observation)	Predicted by System	Accuracy (%)
Unripe	5 samples	4 correctly classified	90%
Semi-Ripe	5 samples	5 correctly classified	100%
Ripe	5 samples	4 correctly classified	90%
Overripe	5 samples	4 correctly classified	90%
Overall Accuracy	-----	-----	92.5%

Table 3. System Performance Summary

C. Hardware Prototype

Fig 3. The hardware prototype of the **Smart Fruit Ripening System** is built using an ESP32 microcontroller integrated with sensors to monitor fruit ripeness parameters such as ethylene gas, temperature, humidity, colour, and weight. The collected data is displayed on an LCD and transmitted to the Blynk IoT platform via Wi-Fi for real-time monitoring and automatic control of the fruit storage environment.

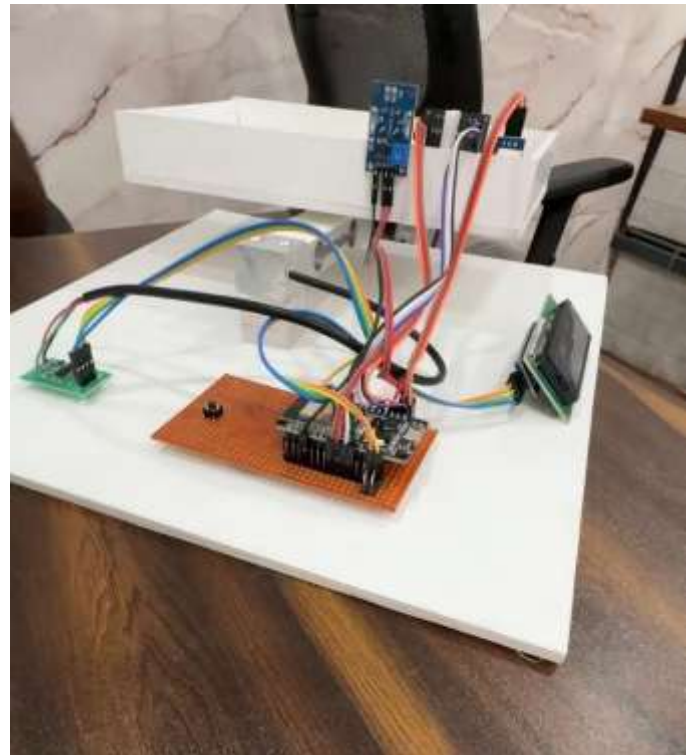
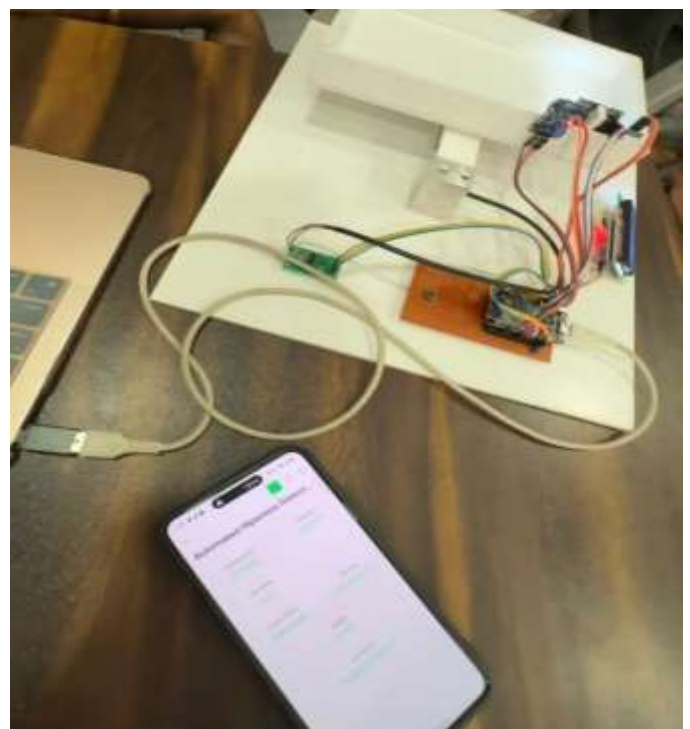


Fig 4. Hardware---ESP32,LCD,load cell and sensors.



D. Discussion

The results show that combining multiple sensors with machine learning improves the accuracy of fruit ripeness detection. The IoT-based system enables real-time monitoring and reduces human error, while the ML model adapts to different fruit types using sensor data. Although the system faced minor limitations such as a small training dataset, slight misclassification during transition stages, and environmental influences, these can be

improved through larger datasets, better sensor calibration, and advanced AI techniques like CNNs and Tiny ML.

6. CONCLUSIONS AND FUTURE SCOPE

The IoT-based system for preventing faster ripening of fruits and vegetables successfully monitors and controls the key environmental factors ethylene gas concentration, temperature, humidity, and moisture that influence the ripening process. Through the integration of the ESP32 microcontroller with various sensors (MQ2 gas sensor, DHT sensor, moisture sensor, and load sensor), the system automates the management of fruit storage conditions in real-time.

The project demonstrates that:

Ethylene Gas Management: The system effectively detects increased ethylene levels using the MQ2 sensor and, in response, automatically activates the DC pump to spray an ethylene absorbent. This action helps slow down the ripening process and prolongs the shelf life of the produce.

Environmental Control: When temperature, humidity, or moisture exceed safe thresholds, the system triggers the DC fan to ensure proper air circulation, maintaining optimal conditions within the storage container.

Real-Time Monitoring and Control: All sensor data are displayed on the LCD and transmitted to the Blynk IoT platform, allowing for remote monitoring and control via a smartphone. Alerts are generated in case of abnormal conditions, providing real-time updates to the user.

Overall, the system achieves its goal of reducing post-harvest losses due to premature ripening. By automating the monitoring and response to environmental changes, the system minimizes human intervention and enhances efficiency in the storage and transportation of fruits and vegetables. This solution offers a cost-effective, energy-efficient, and user-friendly approach to extending the shelf life of produce, making it highly suitable for use in agriculture and food storage industries.

FUTURE SCOPE

The future scope of the Smart Ethylene Management System focuses on making it more intelligent, efficient, and suitable for real-world agricultural use. It includes integrating advanced AI and Tiny ML for better ripeness prediction, adding image-based detection using cameras, and automating environmental control of temperature, humidity, and airflow. The system can also be enhanced with solar power, cloud-based analytics, mobile or voice control, support for multiple fruit types, wireless sensor networks, and large-scale industrial testing. These improvements will increase accuracy, automation, sustainability, and commercial applicability of the system.

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