

AgriPreserve: Intelligent Cold Storage System and Supply Optimization Platform for Agricultural Products

1st Prof. Pratiksha Pansare

Department of Computer Engineering
Samarth College Of Engineering And
Management
Pune, India
pratupansare7@gmail.com

2nd Yash Thorat

Department of Computer Engineering
Samarth College Of Engineering And
Management
Pune, India
yashthorat1912@gmail.com

3rd Tanmay Kanase

Department of Computer Engineering
Samarth College Of Engineering And
Management
Pune, India
tanmaykanase07@gmail.com

4th Sanket Pardhi

Department of Computer Engineering
Samarth College Of Engineering And
Management
Pune, India
pardhisanket199@gmail.com

Abstract— The integration of intelligent monitoring systems, Internet of Things (IoT), Artificial Intelligence (AI), and data-driven optimization technologies is transforming post-harvest management. AgriPreserve proposes an Intelligent Cold Storage System and Supply Optimization Platform designed to enhance preservation, reduce post-harvest losses, and improve distribution efficiency for agricultural produce. This review paper surveys recent advancements from 2019–2025 in IoT-enabled cold storage monitoring, AI-based shelf-life prediction, smart inventory management, and supply chain optimization platforms for perishable commodities.

Keywords— Intelligent Cold Storage, Agricultural Produce, Internet of Things (IoT), Predictive Analytics, Temperature and Humidity Monitoring, Energy-Efficient Storage, Artificial Intelligence (AI), Real-Time Monitoring.

I. INTRODUCTION

Fruits are highly perishable agricultural products that require controlled storage conditions to maintain their quality, freshness, and market value. Improper handling and lack of efficient storage systems often lead to significant post-harvest losses, especially in developing countries. Factors such as temperature fluctuations, humidity imbalance, and the accumulation of spoilage gases like ethylene accelerate the ripening process and result in rapid deterioration of fruits. Traditional cold storage systems primarily rely on manual monitoring and fixed control mechanisms, which are often inefficient and prone to human error. These systems lack real-time monitoring capabilities and are unable to adapt dynamically to changing environmental conditions. Moreover, they do not provide predictive insights that can help farmers and storage operators make informed decisions regarding storage duration and market supply. To address these challenges, this paper proposes *AgriPreserve*, an intelligent cold storage system and supply optimization platform specifically designed for fruit preservation. The system integrates Internet of Things (IoT) technology with

artificial intelligence (AI) to enable continuous monitoring and automated control of environmental parameters such as temperature, humidity, and gas concentration. An ESP32-based sensor network collects real-time data, which is processed and stored on a cloud platform for analysis and visualization. In addition to maintaining optimal storage conditions, the system incorporates a predictive analytics module that estimates fruit shelf life and supports supply optimization. By analysing environmental trends and storage data, the system assists in reducing spoilage and improving inventory management. The proposed solution aims to minimize post-harvest losses, enhance storage efficiency, and provide a scalable and cost-effective approach for modern agricultural practices. Inconsistent storage conditions not only reduce the shelf life of fruits but also affect their nutritional value and market pricing. The integration of IoT and AI technologies enables real-time decision-making and predictive insights, which are essential for optimizing storage duration and ensuring timely distribution. By combining intelligent monitoring with supply optimization, the proposed system bridges the gap between storage management and market dynamics, ultimately helping farmers maximize profits while maintaining product quality.

II. OBJECTIVES

The primary objectives of this review paper are:

- To automate the monitoring of temperature, humidity, and spoilage gases in cold storage using IoT sensors, ensuring that crops are maintained under optimal conditions and reducing the risk of deterioration.
- To reduce manual intervention by implementing automated cooling and humidity control based on product needs.
- To improve storage efficiency and accuracy by maintaining a comprehensive product database with

shelf-life information, allowing proper scheduling and tracking of stored produce.

- To enable timely alerts and notifications when stored produce nears the end of its preservation period, ensuring proactive action to prevent spoilage and financial loss.
- To allow farmers and storage operators to remotely access and control the system via Android platforms, ensuring convenience, flexibility, and continuous monitoring from any location.
- To enhance decision-making using predictive analysis and machine learning.
- To ensure user-friendly interfaces for mobile applications, making the system accessible to non-technical users, including small-scale farmers.
- To contribute to reduced post-harvest losses, improved product safety, and increased profitability, ultimately supporting farmers' income and livelihood.
- To create a scalable and sustainable system that can be expanded to larger warehouses and multiple storage facilities, ensuring long-term adoption and supporting modern agricultural practices.

III. LITERATURE REVIEW

A. Remote Monitoring System for Cold Storage Warehouse using IoT

The paper titled "Remote Monitoring System for Cold Storage Warehouse using IoT" presents a comprehensive IoT-based framework designed to enable continuous and remote monitoring of environmental conditions within cold storage facilities. The system architecture typically includes temperature and humidity sensors interfaced with a microcontroller unit such as Arduino or ESP-based devices, which are responsible for collecting real-time environmental data. This data is transmitted to a cloud platform using wireless communication protocols such as Wi-Fi, Zigbee, or MQTT, ensuring reliable and efficient data transfer. The cloud infrastructure provides data storage, processing, and visualization through user-friendly dashboards accessible via web or mobile applications. The system also incorporates threshold-based alert mechanisms that notify users when environmental parameters exceed safe limits, thereby enabling timely intervention. Furthermore, the availability of historical data allows for trend analysis and performance evaluation of storage conditions over time. Despite these advantages, the system operates primarily as a monitoring solution without implementing a closed-loop control system. It does not include actuators or automated mechanisms to regulate temperature and humidity based on sensor feedback. Additionally, the absence of predictive analytics limits its capability to forecast potential spoilage or optimize storage conditions proactively, making it less effective for highly perishable commodities such as fruits.

B. IoT-based Smart Cold Storage System for Efficient Stock Management

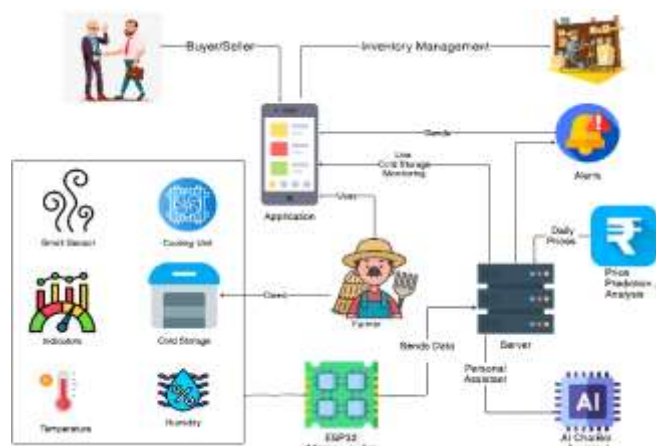
The research work "IoT-based Smart Cold Storage System for Efficient Stock Management" focuses on improving the efficiency of inventory handling within cold storage environments through the integration of IoT technologies. The system combines environmental sensing with product identification techniques such as RFID tags or barcode systems to enable real-time tracking of stored goods. Each product is uniquely identified and monitored throughout its storage lifecycle, allowing for accurate record-keeping and improved traceability. Sensor data related to temperature and humidity is integrated with inventory data to provide a comprehensive overview of storage conditions and stock status. The system supports automated inventory management strategies, including First-In-First-Out (FIFO), which ensures that older stock is utilized before newer stock, thereby reducing wastage. Additionally, the use of cloud-based databases enables centralized data access, facilitating better coordination between storage operators, suppliers, and distributors. The system significantly reduces manual effort, minimizes human error, and enhances operational transparency. However, the primary focus of this approach is on stock management rather than environmental optimization. It lacks real-time adaptive control mechanisms for regulating storage conditions and does not incorporate intelligent algorithms for predicting shelf life or spoilage risks. Consequently, while it improves inventory efficiency, it does not fully address the preservation challenges associated with highly perishable products such as fruits, which require precise and dynamic environmental control.

C. Improving Cold Chain Logistics through RFID Temperature Sensing and Predictive Modelling

The paper "Improving Cold Chain Logistics through RFID Temperature Sensing and Predictive Modelling" introduces an advanced system aimed at enhancing the efficiency and reliability of cold chain logistics through the integration of RFID technology, temperature sensing, and predictive analytics. In this approach, RFID tags equipped with temperature sensors are attached to perishable goods, enabling continuous monitoring of environmental conditions throughout the transportation process. These smart tags record temperature variations at regular intervals and transmit the data to a central system for analysis. The collected data is processed using predictive models, which may include statistical methods or machine learning algorithms, to estimate product quality degradation and remaining shelf life based on environmental exposure. This enables stakeholders to make informed decisions regarding transportation routes, storage adjustments, and delivery schedules, thereby reducing the risk of spoilage and improving overall supply chain efficiency. The system also enhances traceability, ensuring compliance with cold chain standards and providing transparency across the supply chain. However, the scope of this system is primarily limited to the logistics and transportation phases, with minimal focus on storage-level automation. It does not include mechanisms for real-time environmental control within cold storage facilities, nor does it integrate actuator-based responses to changing conditions.

As a result, while it significantly improves monitoring and prediction during transit, it does not fully address the challenges of maintaining optimal storage conditions for perishable fruits within cold storage environments.

IV. SYSTEM DESIGN AND ARCHITECTURE



The proposed AgriPreserve system is designed as an integrated IoT and AI-based platform for intelligent cold storage and supply optimization of fruits. The architecture consists of four major layers: sensing layer, control layer, cloud layer, and application layer, all working together to ensure real-time monitoring, automated control, and predictive decision-making. At the sensing layer, multiple sensors are deployed inside the cold storage unit to continuously monitor environmental conditions. The DHT22 sensor is used to measure temperature and humidity, which are critical factors affecting fruit preservation. Additionally, the MQ135 gas sensor is utilized to detect spoilage gases such as ethylene, which indicate the ripening and deterioration of fruits. These sensors provide real-time data reflecting the internal storage environment. The collected sensor data is processed by the ESP32 microcontroller, which acts as the core control unit of the system. The ESP32 reads sensor values and transmits the data to the cloud server via Wi-Fi. It also controls actuators such as cooling systems (fans), LED indicators, and other control mechanisms using relay modules. Based on predefined threshold values, the system automatically activates or deactivates cooling and humidity control devices to maintain optimal storage conditions. The cloud layer is responsible for data storage, processing, and analytics. All sensor readings are sent to the server, where they are stored in a database and analyzed. The system also integrates price prediction and analysis modules, which provide daily market price updates and assist in supply optimization decisions. This enables farmers to determine the best time to sell their produce based on both storage conditions and market trends. An artificial intelligence module is incorporated to enhance system intelligence. The AI chatbot assistant acts as a personal assistant for the farmer, providing recommendations, answering queries, and offering insights based on collected data. Additionally, predictive algorithms analyze historical data to estimate fruit shelf life and detect potential spoilage risks in advance. At the application layer, a mobile or web-based application provides an interface for users to monitor and control the system

remotely. The application displays real-time sensor data, storage conditions, and alerts. It also sends notifications to the user whenever abnormal conditions are detected, enabling immediate action. Farmers can access live cold storage monitoring, view price trends, and interact with the AI assistant through this interface. Overall, the system ensures seamless integration between hardware and software components, enabling automated environmental control, real-time monitoring, and intelligent decision-making. This architecture significantly reduces manual effort, minimizes post-harvest losses, and improves the efficiency of fruit storage and supply chain management.

V. IMPLEMENTATION

The proposed project titled “AgriPreserve: An Intelligent Cold Storage System and Supply Optimization Platform for Agricultural Products” aims to provide an integrated solution for efficient storage and management of perishable fruits. The system uses IoT technology to monitor temperature, humidity, and spoilage gases in real time, ensuring optimal storage conditions. It also incorporates AI-based analysis to predict shelf life and support supply optimization decisions. The system combines sensors, a microcontroller, cloud services, and a mobile application to enable automated control and remote monitoring. Real-time alerts and notifications help users take immediate action in case of abnormal conditions, reducing post-harvest losses and improving storage efficiency.

A. Technologies Used:

The project’s vision is to develop a unified smart cold storage ecosystem that connects farmers, storage operators, and markets through real-time monitoring and intelligent decision-making. The system integrates Internet of Things (IoT), cloud computing, and artificial intelligence within a multi-layered architecture to ensure efficient storage, reduced spoilage, and optimized supply management of perishable fruits.

Category	Technology Used
Hardware	ESP32, DHT22 (Temperature & Humidity), MQ135 (Gas Sensor), Relay Modules
Frontend	Flutter (Mobile/Web Application)
Backend	Node.js with TypeScript
Database	MongoDB
Deployment	Render
Communication	HTTP over Wi-Fi
Visualization	Charts.js
AI Module	Shelf-life prediction and chatbot assistant

VI. TESTING AND EVALUATION

Testing is a crucial phase to ensure that the proposed smart cold storage system functions accurately, reliably, and efficiently. The system is evaluated using unit testing and integration testing to validate both individual components and their interaction. These tests help ensure real-time monitoring, automated control, and seamless communication between hardware and software modules.

A. Unit Testing:

Unit testing is performed to verify the functionality of individual modules independently.

- 1) **Sensor Module Testing:** Temperature and humidity sensors (DHT22) and gas sensor (MQ135) were tested to ensure accurate and stable readings under different environmental conditions.
- 2) **Data Acquisition Unit Testing:** Sensor data was successfully collected and processed by the ESP32 microcontroller. Sampling rate, calibration, and accuracy of readings were verified.
- 3) **Cloud Database Testing:** The cloud database successfully stored and retrieved real-time and historical sensor data without data loss.
- 4) **Control System Testing:** Relay modules controlling cooling fans and indicators were tested to ensure proper ON/OFF operation based on threshold conditions.
- 5) **Application Testing:** The mobile application displayed real-time data accurately and provided proper alerts and notifications to users.
- 6) **AI Module Testing:** The prediction module generated reasonable shelf-life estimates, and the chatbot assistant responded correctly to user queries.

B. Integration Testing:

Integration testing ensures smooth interaction between all system modules.

- 1) **Sensor to Microcontroller Integration:** Sensors were interfaced with ESP32, and real-time data acquisition was verified under normal and varying conditions.
- 2) **Microcontroller to Cloud Integration:** Sensor data was transmitted to the cloud server via Wi-Fi. Data transfer reliability and reconnection after network failure were tested.
- 3) **Cloud to Application Integration:** Stored data was successfully fetched and displayed in the application dashboard with minimal delay.
- 4) **Control System Integration:** Automated control actions (cooling and humidity regulation) were triggered correctly based on sensor data and threshold logic.
- 5) **AI and Data Integration:** The AI module analyzed stored data and provided predictions and recommendations through the application interface.

VII. RESULTS AND DISCUSSION

A. Discussions:

The analysis of IoT-based cold storage systems highlights a significant improvement over traditional storage methods used in agriculture. Conventional storage systems rely heavily on manual monitoring and periodic inspection, which often leads to inconsistent environmental conditions and increased post-harvest losses, especially for perishable fruits. In contrast, the proposed IoT-enabled system ensures

continuous and real-time monitoring of critical parameters such as temperature, humidity, and spoilage gases without human intervention. The integration of IoT with cloud computing enhances data accessibility and reliability. Sensor data is automatically collected and stored on the cloud, enabling users to monitor storage conditions remotely through mobile or web applications. This reduces dependency on manual supervision and allows timely detection of abnormal conditions. Additionally, automated control mechanisms improve system efficiency by maintaining optimal storage conditions through intelligent activation of cooling and humidity control devices. The incorporation of artificial intelligence further strengthens the system by enabling predictive analysis. The AI module analyzes historical sensor data to estimate shelf life and detect potential spoilage risks in advance. This helps farmers take proactive actions, such as adjusting storage conditions or planning timely sales. Moreover, the integration of market price analysis allows users to make informed decisions regarding the best time to sell their produce, thereby improving profitability. Despite these advantages, certain challenges remain in practical implementation. The initial cost of IoT devices and setup can be a barrier for small-scale farmers. Reliable internet connectivity is essential for real-time monitoring, which may not always be available in rural areas. Additionally, sensor calibration and maintenance are required to ensure long-term accuracy. Addressing these challenges through cost-effective hardware solutions and improved connectivity infrastructure can enhance the adoption of smart cold storage systems.

B. Results:

The system was tested under different environmental conditions to evaluate its performance in monitoring and maintaining optimal storage conditions for fruits. The results demonstrate that the system effectively tracks temperature, humidity, and gas levels, and performs automated control actions when required.

Sr No	Condition	Temp (°C)	Humidity (%)	Gas Level (ppm)	System Status
1	Normal Storage	4.5	85	120	Optimal
2	High Temp	9.2	80	130	Cooling Activated
3	Low Humidity	5.0	60	110	Humidity Control Activated
4	High Gas Level	5.5	82	300	Alert Generated
5	Stable Condition	4.8	88	115	Optimal
6	Extended Storage	6.5	78	250	Spoilage Risk Detected

Table 1: Sensor Readings and System Response

VIII. FUTURE SCOPE

Future research and development may focus on:

- Integration of advanced AI and predictive analytics
- Development of self-calibrating IoT sensors
- Implementation of solar-powered IoT systems
- Use of digital twin technology for storage optimization
- Integration of edge computing for faster processing
- Expansion to full supply chain tracking
- Support for multi-storage and large-scale deployment

IX.CONCLUSION

The system successfully enables real-time monitoring of temperature, humidity, and spoilage gases, ensuring optimal storage conditions and reducing post-harvest losses. Automated control mechanisms further enhance system efficiency by minimizing manual intervention and maintaining environmental stability. The integration of cloud computing and mobile applications allows users to remotely monitor and control the storage system, improving accessibility and convenience. Additionally, the incorporation of AI-based predictive analysis supports better decision-making by estimating shelf life and identifying potential spoilage risks in advance. Overall, the system demonstrates reliability, scalability, and practical applicability in modern agricultural practices. It contributes to improved storage efficiency, reduced wastage, and increased profitability for farmers, making it a valuable solution for smart agriculture and cold chain management.

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