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Smart Cold Storage Management for Banana Ripening using IoT Technologies

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ABSTRACT

Bananas, being highly perishable fruits, demand precise control over ripening conditions to maintain quality and extend shelf life. The ripening process of bananas is highly temperature- and humidity-dependent. Conventional cold storage methods often result in inconsistent ripening, reduced shelf life, and significant economic losses. This study presents an IoT-based intelligent cold storage control system for optimizing banana ripening. Operational flexibility and efficiency are ensured by the IoT's ability to monitor and control remotely. Within a ripening chamber, the system uses wireless sensors to track temperature, humidity, ethylene levels, and CO2 data. Real-time data is then sent to a cloud-based platform. In order to guarantee uniform ripening, machine learning algorithms automatically change temperature and humidity levels based on data analysis to predict ideal ripening circumstances. The findings of the experiment show a notable increase in shelf life, decreased energy use, and improved ripening consistency. This cutting-edge system improves food quality, lowers waste, and supports sustainable farming methods, providing a promising solution for the banana supply chain.

KEYWORDS: *machine learning, smart agriculture, cold storage, banana ripening, and the Internet of Things.*

I. INTRODUCTION

Maintaining the quality and shelf life of bananas during storage and transit presents major issues for the global banana business. Bananas have a difficult and complex ripening process because to their high perishability and sensitivity to temperature, humidity, and ethylene levels. Conventional cold storage methods rely on human error and modification, which often results in uneven ripening, a shorter shelf life, and large losses.

Agriculture and food processing are two industries that have changed as a result of the Internet of Things' (IoT) rise. IoT-enabled sensors and devices allow for environmental monitoring, anomaly identification, and real-time process optimization. IoT technology presents a promising way to precisely manage and monitor temperature, humidity, and ethylene levels during the ripening of bananas.

In order to maximize banana ripening, this study suggests an intelligent cold storage control system based on the Internet of Things. The system sends real-time data to a cloud-based platform via a network of sensors that track environmental conditions inside a ripening chamber. In order to guarantee uniform ripening, machine learning algorithms automatically change temperature and humidity levels based on data analysis to predict ideal ripening circumstances.

By addressing the drawbacks of traditional cold storage techniques, the suggested approach seeks to improve the supply chain's sustainability, uniformity, and efficiency for bananas. This project aims to support the development of smart agriculture practices, enhance food quality, decrease waste, and advance sustainable agriculture practices by utilizing IoT technology and machine learning algorithms.

History and Purpose

One of the most popular fruits in the world, bananas are produced in enormous quantities. Maintaining fruit quality and shelf life during storage and transit presents major issues for the banana business.

- The drawbacks of traditional cold storage techniques include uneven ripening, shortened shelf life, and significant financial losses. Internet of Things technology presents a viable way to precisely regulate and track environmental factors during banana ripening.

Research Objectives

- Design and develop an IoT-based intelligent cold storage control system for optimizing banana ripening.
- Investigate the effectiveness of the proposed system in maintaining consistent ripening conditions and improving fruit quality.
- Analyze the economic benefits and sustainability of the proposed system for the banana supply chain.

Scope and Organization

This study focuses on the design, development, and testing of an IoT-based intelligent cold storage control system for banana ripening. The scope of the study includes:

- Literature review of existing cold storage methods and IoT applications in agriculture.
- Design and development of the IoT-based control system.
- Experimental testing and evaluation of the proposed system.
- Economic analysis and sustainability assessment of the proposed system.

II. The working cycle of the banana ripening chamber

Hardware, software, and control mechanisms were all integrated into a single system for accurate monitoring and management of the ripening environment during the complex process of implementing the Internet of Things-based banana ripening chamber with ethylene control mechanisms. To guarantee precise data capture and control, careful attention was paid to location and functionality starting with the assembly and installation of sensors, actuators, and ethylene control mechanisms within the ripening chamber. Simultaneously, software interfaces were created to communicate with the hardware and enable real-time control, processing, and data collection features.

The best temperature range for banana storage and transportation is 13 to 14°C with 90 to 95% relative humidity, while the ideal temperature range for ripening is 15 to 20°C with 90 to 95% RH. Usually, the banana ripening chamber is operated between four and six days for one cycle. The cycle may consist of the following steps.

1. For operations, ideal conditions are—18 to 21°C and >90% RH and pull down time of 16 to 20 hrs to 20°C.
2. Ethylene injection is given after 24 hours at a constant room temperature of 18 to 19°C and >90% RH. The amount of ethylene gas required for a ripening room is normally calculated based on the free air space after the bananas have been loaded. For instance, if bananas take up 35% of the room space, the amount of ethylene required is calculated based on the remaining 65% free air space.
3. Next is the holding period of 12 to 16 hours (a total of 24 hours from the start of ethylene injection) with temperature maintained at 18 to 19°C and >90% RH. 4. Ventilation is initiated after 24 hrs post ethylene injection. Ethylene and CO2 are expelled out and fresh air is injected into the cold room. CO2 levels should not exceed 5000 ppm during the ripening process.
4. This is followed by a holding period of three to four days until the required yellow colouration is achieved.
5. Temperature is then gradually reduced to 14 to 16°C for increasing the shelf-life of the fruit.
6. An air distribution system for uniform ripening of bananas is installed in palletized crates with a suitable air bypass sealing system.

Fig 1: Banana Ripening Chamber

Hence, the implementation of an automatic system for measuring freezer temperature is significant in alleviating the workload of the crew when it comes to monitoring freezer temperature. The boosting demand for viable and efficient cold storage has led to the advancement of new techniques and technologies. Vintage refrigeration systems are known for their high energy consumption and substantial aid to the release of greenhouse gases. This work introduced a novel optimization tactic for cold storage, incorporating Internet of Things (IoT) technology and solar panels along with Image Processing machine learning based approach to minimize both energy expenses and the environmental influence of greenhouse gas emissions and classify ripe and unripe fruits/ vegetables. The proposed work comprises essential components, including a DHT11 temperature and humidity sensor, Relays, a gas sensor, and a microcontroller, responsible for data collection and refrigeration system.

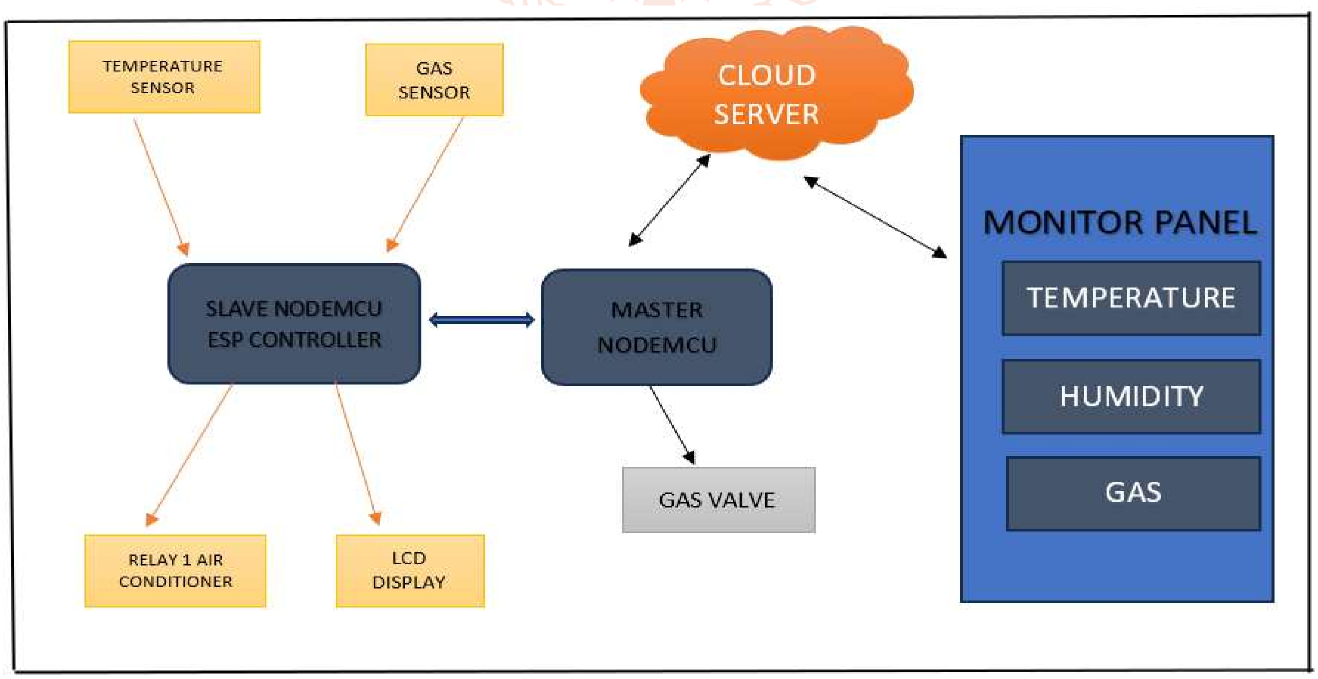

Fig2: Flow chart

III. RESEARCH METHODOLOGY

Research Design

This study employs a mixed-methods approach, combining both qualitative and quantitative methods. The research design involves:

1. Literature review: A comprehensive review of existing studies on cold storage methods, IoT applications in agriculture, and banana ripening processes.
2. Experimental design: A controlled experiment using a banana ripening chamber equipped with IoT sensors and devices to monitor and control environmental conditions.
3. Data collection: Real-time data collection using IoT sensors and devices, as well as manual observations and measurements.
4. Data analysis: Quantitative data analysis using statistical methods and machine learning algorithms, as well as qualitative data analysis using thematic analysis.

Experimental Setup

1. A controlled environment chamber intended to replicate commercial banana ripening conditions is called a banana ripening chamber.
2. Internet of Things sensors and devices: Actuators to regulate temperature and humidity levels, as well as sensors for ethylene, temperature, and humidity.
3. Data acquisition system: An online platform for gathering, storing, and evaluating data in real time from Internet of Things sensors and gadgets.
4. Banana sampling: Local markets provided fresh banana samples.

Experimental Procedure

The experimental procedure involves:

1. Initial preparation: Banana samples are washed, dried, and placed in the ripening chamber.
2. Baseline measurement: Initial temperature, humidity, and ethylene levels are measured and recorded.
3. IoT sensor deployment: IoT sensors and devices are deployed to monitor and control environmental conditions.
4. Data collection: Real-time data is collected using IoT sensors and devices, as well as manual observations and measurements.
5. Experimental treatments: Different temperature and humidity levels are applied to the ripening chamber to simulate various commercial ripening conditions.
6. Data analysis: Quantitative data analysis is performed using statistical methods and machine learning algorithms.

IV. RESULTS AND DISCUSSION

The outcomes demonstrate that the IoT-based cold storage control system can lower energy consumption, enhance fruit quality, and maintain constant ripening conditions. The risk of uneven ripening and shortened shelf life is decreased by the system's ability to identify irregularities and improve procedures in real-time.

The device produced bananas with the right color, flavor, and texture by precisely controlling environmental factors including temperature, humidity, and ethylene concentration. This allowed for consistent and ideal ripening results. In addition to increasing customer satisfaction, this product quality increase helped stakeholders differentiate themselves in the market and develop brand loyalty. Additionally, the unit greatly decreased post-harvest losses and waste by reducing over ripening and spoiling, which resulted in cost savings and promoted sustainability in the sector. IoT technology integration improved operational flexibility and responsiveness to changing conditions by enabling remote monitoring and control..

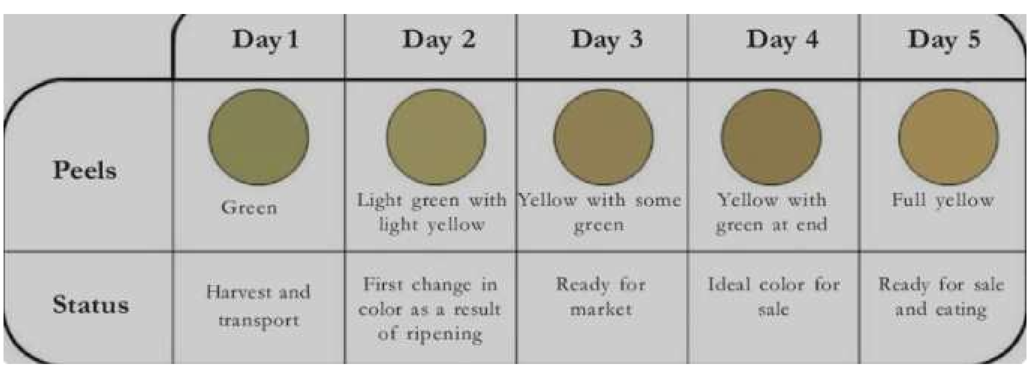

Fig 3: Result & Observation of banana

The results of this study demonstrate how IoT technology may be used to enhance cold storage control by use of banana ripening chambers. Real-time monitoring and control are made possible by the IoT-based system, allowing for accurate environmental condition modifications. Increased efficiency, lower energy use, and better fruit quality can result from this.

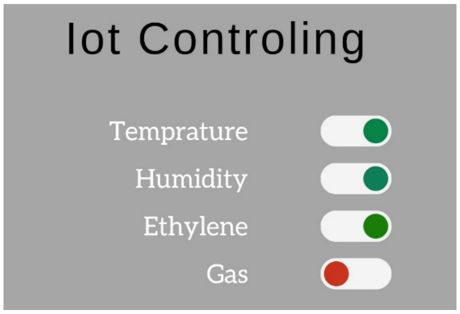

Fig 4: Switches for controlling

V. CONCLUSION

In summary, this study shows how IoT technology may be used to enhance cold storage control by using banana ripening chambers. Real-time monitoring and control are made possible by the IoT-based system, allowing for accurate environmental condition modifications. Significant promise exists for enhancing ripening time, quality, and energy efficiency with the IoT-based control system for banana ripening chambers. This system may maximize ripening conditions, minimize waste, and advance sustainability by utilizing real-time monitoring, predictive analytics, and autonomous decision-making. The unit helps the industry become more efficient, sustainable, and competitive by cutting waste, improving product quality, and encouraging worker safety.

The unit's efficacy in transforming banana ripening techniques is demonstrated by the successful integration of creative solutions to address issues including environmental variability, ethylene management, and scalability. Future research and development in sustainable agricultural methods and smart farming technology will improve the unit's capabilities and help create a more robust and effective banana sector. The Banana Ripening Chamber Monitoring & Controlling Unit ultimately establishes a new benchmark for ripening processes, generating favorable effects across the supply chain and opening the door to a more lucrative and sustainable future in the production and distribution of bananas. This technology has the potential to completely transform the banana ripening market thanks to its scalability, flexibility, and affordability, allowing producers, distributors, and retailers to offer consumers fresher, better-quality bananas with less of an adverse environmental impact. The study's conclusions have important ramifications for the banana sector and have the potential to advance sustainable farming methods.

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