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AI-Enabled Smart Storage System for Onions

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1***Abstract*— This is a sustainable and smart solution to diminish the impact of post-harvest spoilage of onions, which leads to a significant loss of money and variation in market pricing. Traditional storage methods cannot monitor and control in a scientific manner resulting in large losses of onions *(30–40%)*, and resources such as water, electricity, and labor. The smart and affordable solution that is friendly to farmers uses sensors and AI/ML-based analytics that continuously monitor and maintain ideal storage conditions. The sensors detect *temperature, humidity, and gas concentration*. The condition is maintained only by controlling fans, heaters, and infrared lamps when required, ensuring the conservation of energy and reliability. The farmer will be notified through local alerts such as buzzers and light or alarms which will function even without internet connectivity keeping the farmer or cold storage operator informed about the immediate warning. The system also provides easy-to-implement and feasible future recommendations to correct the storage situation (ventilation, charcoal, etc.). The multilingual interface and low need for resources (land, water, and electricity) make the system adaptable to a variety of crops and storage and market scales. To make it even more sustainable, an optional solar-powered system could also be implemented. Together, the system using sensors, automation, and embedded *AI/ML intelligence* minimizes spoilage, improves onion quality and allows the farmers to sell their stored onions at better quality, which leads to higher income, less post-harvest loss and waste, and provides a cost-effective, sustainable solution that requires less effort to scale overtime**.

***Index Terms*— AI/ML, BLE Gateway, BME680 Sensor, IoT,Post-Harvest Losses, Smart Agriculture, Sustainable Storage.**

I. INTRODUCTION

The nion is an agricultural product, but its storage often leads to major post-harvest losses of about 30–40%, as a result of inefficient storage methods. Traditional storage methods do not offer monitoring and automatic control capabilities in real time, causing degradation of product quality from temperature, humidity, and gas concentration fluctuations.

This paper discusses a sustainable and smart onion storage system that uses sensors, automation, and AI/ML-based analysis methods to ensure a reduction in post-harvest losses. The objective is to reduce the post-harvest loss and increase the shelf life of onions by maintaining storage conditions and utilizing energy efficiently leading to increase in farmer's profits by auto climate control and helping in sustainable agricultural practices.

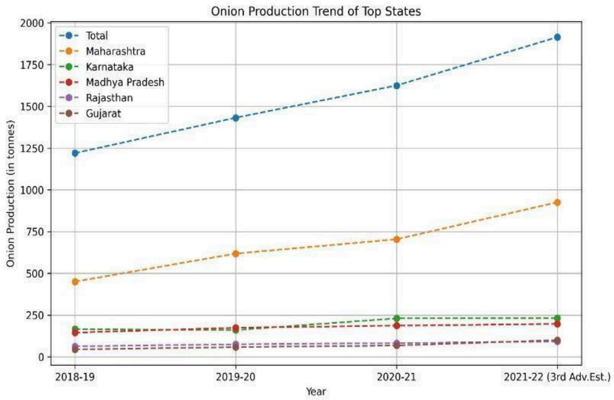

Fig. 1. Onion Production trend of Top States

II. Literature Review

Post-harvest onion losses is a constant problem in India which results in spoilage rate of 30–40% due to poor temperature, humidity, and ventilation control. Many studies and government reports have emphasized on the need for controlled storage environments.

1 *ICAR (Indian Council of Agricultural Research)* suggests storage conditions of 25–30°C and 65–75% relative humidity to reduce sprouting and decay.
2 *PIB (2024) and MNRE initiatives* (PM-KUSUM) highlight solar-based Agri-solutions but do not integrate AI-based spoilage prediction.
3 *Kumar et al. (2021)* proposed low-cost ventilated structures, but these lack real-time monitoring and automation.
4 *Patil et al. (2022)* explored IoT-based monitoring for grains but not perishable crops like onions.

Recent works in smart agriculture use sensors like DHT11 and MQ135, but their accuracy and calibration are limited compared to BME680, which detects VOCs such as ethylene, a key indicator of onion spoilage.

A. Gap Identified

Existing research mainly focuses on either manual monitoring or by basic IoT sensing. There is limited integration of AI/ML analytics, real-time alerts, and energy-efficient automation in onion storage.

Our proposed system fills this gap by introducing a hybrid AI-enabled, low-cost, sustainable model that is tailored for farmers with minimal resources and that can work even offline.

III. SYSTEM OVERVIEW

A. Proposed Solution:

To tackle the problem of onion spoilage after harvesting due to poor storage conditions, our AI-enabled system provides a practical, data-driven way to keep the storage environment at its best. The system combines automation, Artificial Intelligence and Cyber-Physical System (CPS) technology to continuously monitor, analyses and control the storage conditions. Unlike the traditional storage system that depends on manual checking, this system works automatically by collecting and analyzing real-time data of temperature, humidity and volatile organic compounds (VOCs) including ethylene gas which are an early indicator of spoilage. The system automatically adjusts fans, heaters and infrared lamps to maintain the right conditions and keep the onions fresh for longer period.

The system uses Bluetooth Low Energy (BLE) network to enable easy communication between the sensors, microcontrollers and mobile app. This design keeps everything running smoothly, even in rural areas where internet access might be limited. Farmers can use the app and cloud dashboard to check live data, receive alerts, and monitor the condition of their onions anytime. By integrating AI and machine learning, the system becomes smarter at predicting when spoilage might happen and offers simple ways to prevent it. These predictions help farmers take quick actions, such as adjusting ventilation or humidity, which reduces waste and improves onions' shelf life.

B. Technical Approach:

1. Physical Layer: The system uses BME680 sensors to monitor temperature, humidity and volatile organic compounds (VOCs) mainly ethylene gas which act as an early indicator of onion spoilage. These sensors constantly measure the data of storage to keep records of the conditions. Based on readings, the system automatically adjusts fans, heaters, and infrared lamps to maintain the right storage conditions. It is designed for low power consumption and can operate on solar energy promoting sustainability and cost efficiency. The sensors are carefully placed to cover the entire storage area, ensuring consistent and reliable monitoring.
2. Network Layer: In this layer, the data received from the sensor is sent to a microcontroller via Bluetooth Low Energy (BLE) gateway for further processing. BLE communication provides secure and low power data transfer between devices making the system suitable for rural areas. The network is also designed to work offline allowing the system to function continuously even without internet connection. This ensures reliability in remote areas.
3. Application Layer: The mobile app is available in many languages such as English and Hindi which provides farmers easy access to live reading of temperature, humidity, and air quality inside the storage. It provides alerts through a simple farmer-friendly interface which makes monitoring easy. All the collected data are stored and analyzed on a cloud dashboard (using Firebase), helping farmers track conditions over time. If the temperature, humidity, or gas levels go beyond a certain threshold, the system instantly sends a push notification or WhatsApp alert, allowing farmers to act quickly and prevent spoilage.

4. Action Layer: The action layer is designed for generating real-time responses based on the data analyzed. The system automatically adjusts actuators such as fans, heaters, and infrared lamps whenever the conditions go out of the predefined thresholds. To notify the farmer immediately, local alerts like buzzers and indicator lights and remote alerts (via the mobile app) are also activated at the same time. The system also suggests preventive measures such as enhancing ventilation or using charcoal absorbers to stabilize environmental conditions and minimize storage losses.

5. AI/ML Integration: An AI/ML model is added to predict future spoilage by analyzing real-time and recorded data. The model then gives early warnings and corrective suggestions that help to maintain onion health and quality. With the help of predictions, we can take required actions to control the conditions, save energy, and reduce post-harvest losses. This layer makes the system more active ensuring longer shelf life and improved sustainability.

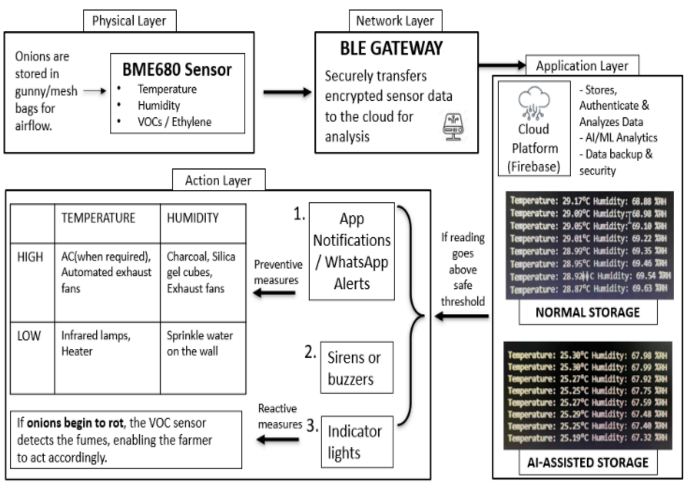

Fig. 2. Layered Architecture

IV. FUTURE WORK

In the future, the system can be upgraded by designing a VOC detection probe to accurately locate the areas of spoilage in the storage chamber. This probe will measure gas levels at different locations, and the spoilage zone can be indicated through LED colors: green for safe conditions, yellow for moderate, and red for high risk. This indication will allow areas quickly, prevent further spoilage, and also result in reduced losses.

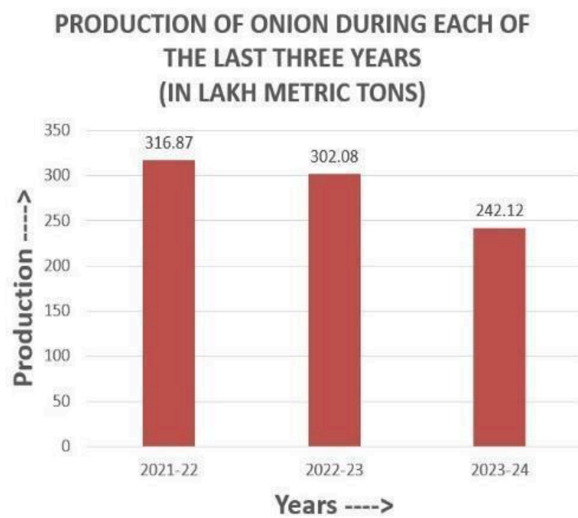

Fig. 3 Onion Production trend of Top States

A. A Look at Sustainability and Energy

1. Efficiency of Power

In order to minimize unnecessary power consumption, the system only activates actuators when thresholds are exceeded.

2. The Option of Solar Power

An optimal solar powered setup improves system sustainability by reducing dependence on traditional electricity and ensures optimal use of energy.

V. FINDINGS AND DISCUSSIONS

Prototype-level testing and simulations were executed to evaluate the practicability and expected performance of the developed smart onion storage system. The system successfully maintained stable environmental conditions as recommended by Indian Council of Agricultural Research approximately *25–30 °C temperature and 65–75% relative humidity* which are usually considered optimal for onion storage.

During initial experiments, the sensor network and control unit responded effectively to environmental fluctuations by activating the fan and heating elements only when required. This resulted in a more *controlled storage environment* inside the chamber, unlike the fluctuations in ambient storage where temperature and humidity were varying widely throughout the day. The real-time monitoring setup successfully identified variations *in temperature, humidity, and VOC concentration*, validating its effectiveness for early spoilage detection. The alert system provided timely local notifications via buzzers and indicator lights (when offline) if any parameter whether it is temperature, humidity or VOC level crosses its safe range, ensuring reliability of the automation and connectivity modules.

Initial observations also indicated that *AI/ML analytics* integration could help recognize spoilage trends and propose preventive measures such as improved ventilation or dehumidification techniques like the use of charcoal or silica gel bags. These results highlight the ability of the system to increase onion shelf life**,** reduce post-harvest losses, and minimize the need for manual monitoring, making it a practical, cost-effective, and sustainable solution for farmers across the world.

VI. Conclusion

This paper presents an AI-powered, sustainable and cost-effective solution for management of onion storage that addresses the challenges of post-harvest onion loss and no manual monitoring. The paper offers smart sensing, automation, and data analytics. Through this the system ensures better quality of onions, reduces waste, and highly profitable production for farmers.

It is multilingual which can easily be understood by any farmer across diverse regions of India, and has an adaptable design, which makes the system suitable for other perishable crops such as potatoes, tomatoes, garlic, leafy vegetables that lose freshness quickly, fruits like bananas, mangoes and apples that emit ethylene gas and accelerate ripening which enables the system to be highly scalable and sustainable in the agriculture sector.

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