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Systematic Storage Management System for Eco Friendly Agriculture Using IoT

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Abstract: Efficient storage of harvested crops true is a key to reduce post-harvest losses and guarantee a good quality on the food, whereas traditional storage systems generally are not equipped to dynamically control environmental conditions. This paper proposes a Systematic Storage Management System (SSMS) to eco-agriculture base on Internet of Things (IoT) to realize the automation of monitoring and controlling of storage key parameter. The proposed system combines temperature, humidity and gas sensors with microcontroller, and Wi-Fi/LoRa/ZigBee wireless communication modules, permitting real time data acquisition and remote access via cloud platform. Farmaers can view storage conditions control remotely, get alerts in real time ,manage control parameters via web & mobile based user interface. Given a 7-day experiment, it was proven that the system was able to maintain temperature and humidity at optimal ranges, control ventilation itself depending on the gas concentration, and save up to 20% of energy consumption compared to the traditional solutions. The modular, scaleable design makes the system versatile for variety of agricultural storage application, aiding to Increased sustainability, Reduced spoilage and better food security.

Keywords - *Smart Agriculture, IoT, Storage Management, Environmental Monitoring, Eco-Friendly Farming, Wireless Sensor Network, Cloud Analytics, Precision Agriculture, Energy Efficiency, Post-Harvest Technology.*

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I. INTRODUCTION

Industry is a key socio-economic element of countless countries, especially loads in the facilities. Even with improved farming practices there is a substantial cause of post harvesting loss due to wrong storage. Experiments show that there is considerable amount of the harvest of produce—especially those perishables such as grains, fruits, and vegetables—is being carelessly thrown away because of poor storage, the huge losses to the economy result in and food insecurity.

Traditional storage regulated methods are seldom capable of delivering live time environmental control or management through data. Furthermore, most of these techniques normally need high power consumption and are insensitive to changes in climate conditions. With the climate change and growing pressure on sustainable solutions there is an urgent need for smarter, greener, storage solutions for agriculture. IoT offers an opportunity for transformation here. Through the installation of smart sensors, wireless connectivity and automation it into the storage facilities, enable real-time monitoring and control of important environmental parameters such as temperature, moisture content of point and gas concentration by IoT. These systems not only ensure that the storage condition is maintained perfectly, but also smart automation, lowers the energy consumption.

This paper presents a Systematic Storage Management System (SSMS) for eco-friendly agriculture that utilizes IoT for improving efficiency, sustainability and reliability of the agricultural storage. The suggested system is designed for continuos monitoring, data logging and environmental control, being at the same time, versatile and economical for rural and semi-urban farming communities.

The remaining of the paper is as follows. Section II covers the related work; Section III introduces the system architecture; Section IV describes the implementation and experimental results and Section V concludes the paper.

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II. LITERATURE SURVEY

The integration of Internet of Things (IoT) technology in agriculture has paved the way for substantial momentum due to the wide scope of possibilities that it brings about transforming the existing agricultural practices in its direction towards smart as well as data driven form. Several studies have been conducted on how to use IoT for environmental monitoring and monitoring of precision farming and greenhouses.

IoT-based smart farming platform has come up with the system that can automatically monitor the soil moisture, temperature, crop health to enhance the yield and to cut down the wastage of the resources [1, 2]. Even though the pre-harvest management systems improve the quality of the produce, very limited research work was done on the post-harvest storage, which is one of the most crucial section of the supply chain of agriculture.

The analysis on the storage automation demonstrates that control of temperature and humidity, are the essential conditions to maintain the quality of perishable goods [3], [4]. Sensor-based systems that monitor environmental factors in warehouses and silos have been suggested in research works which enable real-time data acquisition and analytical tools [5, 6].

Cloud computing and wireless communication technologies have been embedded in IoT architecture for remote monitoring/messaging in agricultural application [7], [8]. These technologies also enable big data analytics and predictive maintenance, making them also good for the sustainable development of the system.

Energy efficiency in the storage has been treated by means of the intelligent control algorithms and the low-power sensor networks [9], [10]. But many of them is aimed for industry scale store and is not design for small or ecological agricultura.

Ongoing work has come up with machine-learning based models for the prediction of optimal storage conditions as a function of crop type or ambient conditions [11], but these approaches usually rely on the use of only a very powerful computer, expensive hardware for storage and Internet connection not available in rural areas.

The use of eco-friendly practices in agriculture, such as solar powered storage unit and biodegradable materials, have been looked into in an effort reduce the impact on the environment [12], [13]. These studies make the point that what is needed are systems that integrate technological advance with environmental sustainability.

Several IoT-based storage monitoring prototypes are proposed in the literature, however, they are lacking in real-time decision making for environmental control [14]. Moreover, most of the models do not form a scalable and modular framework that can be tailored for fruits and vegetables of all kinds as well as different storage conditions [15].

This literature review points out the deficit between available smart farming solutions and a comprehensive, environmentally friendly storage management cost system. The proposed project aims to bridge this gap by offering a modular energy-harvesting, energy-efficient, and IoT-enabled storage for agriculture.

III. METHODOLOGY

The proposed Systematic Storage Management System (SSMS) is aimed at monitoring and controlling of key environmental parameters of agricultural storage environments through IoT technology. The system is built of five service-oriented layers: sensor layer, control unit, communication module, cloud storage and analytics, user interface as shown in figure 1.

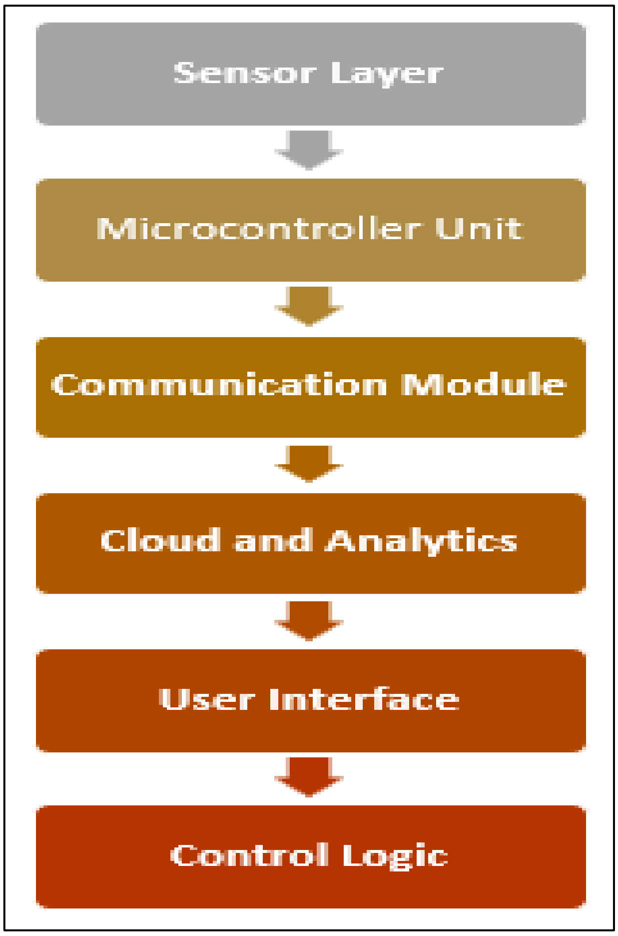

Fig 1 Proposed Architecture

A. Sensor Layer

The Sensor Layer is the heart of the proposed Systematic Storage Management System (SSMS), which offers real time, intelligent monitoring of environmental parameters that are necessary for the preservation of the agricultural produce. This layer is made to collect data accurately from the storage area in use of the low-power, high precision sensor that ensures best condition for different type of crops

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➢ *The following sensors are integrated into the system:*

- *Temperature Sensor (e.g., DS18B20 / DHT22)*
  Used to measure the ambient temperature inside the storage unit. Maintaining a temperature range between 2°C to 25°C is critical to prevent spoilage and reduce microbial activity. These sensors provide high-resolution digital temperature readings with an accuracy of ±0.5°C.

- *Humidity Sensor (e.g., SHT31 / DHT22)*
  Responsible for tracking the relative humidity (RH) levels within the storage area. Most agricultural commodities require humidity levels between 55%–70% to maintain freshness. Deviations can lead to mold growth or desiccation of stored produce.

- *Gas Sensors (e.g., MQ135 for CO_2, MQ137 for NH_3)*
  These sensors detect the buildup of gases such as **carbon dioxide (CO_2)** and **ammonia (NH_3)**, which are indicative of spoilage or biological activity. Controlling gas concentration helps in preventing decay and maintaining air quality inside the storage.

- *Light Sensor (optional) (e.g., BH1750)*
  Included in storage environments where light sensitivity is a concern, such as with onions or potatoes. The light sensor ensures that ambient light levels are within the threshold to prevent sprouting or quality degradation.

➢ *Sensor Calibration and Placement*

Each sensor undergoes calibration using reference standards to ensure accurate measurements. The placement of sensors is strategic:

- *Top Section:*
  To monitor heat stratification.

- *Center:*
  To capture general atmospheric conditions.

- *Bottom:*
  To detect gases and condensation effects.

Data from the sensor layer is collected periodically and transmitted to the microcontroller unit for processing, storage, and actuation decisions. This modular design allows scalability and customization based on crop-specific storage requirements in describe in table1.

Table 1 Sensor Specifications

Sensor Type	Sensor Model	Measurement Range	Accuracy
Temperature	DS18B20 / DHT22	-55°C to +125°C	±0.5°C
Humidity	SHT31 / DHT22	0% to 100% RH	±2% RH
Gas (CO_2)	MQ135	10 – 1000 ppm	±10 ppm
Gas (NH_3)	MQ137	5 – 500 ppm	±5 ppm
Light (Optional)	BH1750	1 – 65535 lux	±20 lux

B. Microcontroller Unit

The Microcontroller Unit (MCU) is central for processing element of proposed Systematic Storage Management System (SSMS). It serves as the middleman between the sensor layer and the cloud-based analytics platform, carrying responsibilities such as data collection and processing, actuation, communication, and so forth. The system utilizes generalised microcontrollers like ESP32, Arduino Uno, criterion based on challenges and communication issues in the execution environment . The ESP32 is used because of its built-in Wi-Fi and Bluetooth, dual core processor and low power consumption, so best suited for wireless IoT. At the same time, the Arduino Uno is a trusted and inexpensive choice for simpler, localized systems.

The MCU continuously reads data from all kinds of attached sensors, such as temperature, humidity, and the gas sensors. It evaluates these inputs when operating by correlating the real-time values against pre-cellure threshold controls. For example, if the temperature exceeds the upper limit, the microcontroller turns on the cooling fan, if relative humidity falls below a minimum - inclusively switches on a humidifier. The decision-making processes within these keepers are managed by aggregated control algorithms controlling timely and exact environmental modifications in the particular Storage device.

In addition to local motion control, the microcontroller converts the sensor data—usually in JSON or other compact formats—and sends it over internet to cloud server or remote screen of remote monitoring by using microcontroller's built-in wireless protocol. The ESP32, in particular, supports seamless integration with MQTT or HTTP protocols for cloud-based applications. Additionally, the microcontroller is power-optimized for sleep-low-power mode encountered during idle periods in order to save power that is ideal for solar or battery application. Adding integration to a Real-Time Clock (RTC) module, allows time-stamping of Data for analytics to understand, and trends to predict. On the whole the microcontroller unit guarantees real-time response, faster data manipulation and efficient communication of the system, all of which play a significant role in intelligent storage management in eco-friendly agricultural systems.

C. Communication Module

The Communication Module is a key part of closing the gap between physical sensing environment and digital monitoring system in proposed Systematic Storage Management System (SSMS). It transmits real-time sensor data from the microcontroller to the cloud or local gateway and so facilitates remote monitoring and control. Depending on the geographical coverage, deployment size, and network availability, the system can be designed to use various

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wireless communication protocols of Wi-Fi, LoRa, and ZigBee.

Wi-Fi is commonly utilised for most near-range and tiny farm storage settings as it is guarantee of a high data rate and availability. It allows for smooth integration with current internet infrastructure and helps to communicate with cloud platforms through MQTT or HTTP. Whereas for remote or remote or vast rural incorporate, where internet signal is restricted, LoRa (Long Range) is the favored option. LoRa provides low-power, long-range communication — up to 10 km out of doors — making it perfect for remote power growing web sites. ZigBee, which is popular for its low power mesh networking capability, is another low power option for sensor devices where devices have to establish a reliable lcoal network.

The communication module is combined with the microcontroller (microcontroller integrated with the (e.g., built-in in ESP32 for WiFi, or as the external modules, e.g. LoRa SX1278 and XBee for ZigBee), it is programmed to send a sensor reading, alert and system log data periodically to cloud platform. The data sent is transmitted encrypted lee selectivamente cryptographic techniques to achieve security and integrity of data, is especially critical for sensitive agricultural commodity.

Additionally, the communication module has a bidirectional data transfer, which also enables the system to send control commands from the counterpart to the user interface in addition to sending sensordata. This allows farmers or administrators remotely update threshold settings, do manual control actions, send real-time alerts through SMS, notification, or email. In general, it is for reliable, safe and energy saving data communication to ensure operational continuity and remotely controled access to smart storage system.

D. Cloud and Analytics

The Cloud and Analytics layer of the suggested Systematic Storage Management System (SSMS) carries out the function of the center for the aggregation of data, storage and processing, and logical insight creation. Once the sensor data is collected and sent by the microcontroller unit is uploaded to the cloud-based infrastructure by using communication protocols like MQTT and HTTP. This cloud infracture going assure scalable and securly storage of large volume of real time data and also will enable for advance analytics and remote access of the System on any internet connected device.

The cloud deck is created to carry on a number of functions. First, there is time-stamped storage of sensor data with parameters such as temperature, humidity, CO_2, and NH_3 concentration. Use of this historical data is essential to establish the long-term patterns, to review the effectiveness of the storage and to get the useful findings. Second, the system conducts real-time analytics by means of statically-defined threshold conditions, possibly also light-weight machine learning models to discover anomalies or environmental moments of change. When a deviation is found out, for example if there is a sudden increase in humidity or gas content, the cloud system immediately reports back to the user via notifications, SMS, or e-mail.

The cloud interface also facilitates data visualization through dashboards showing the current environmental data, history of alert and graph of trends. These dashboards are available from mobile apps or web portal, so that the farmer/facility manager can make an informed decision about the status of their storage conditions even when not on site. Moreover, users have ability to remotely control system setting parameters, including setting up of adjustable acceptable levels of temperature or execution of periodic predetermined actuator actions

For encryption of data, backups and role base access control for data privacy and system resilience, the cloud platform uses encrypted data transfer, backup mechanisms. In addition, the system is capable of integrating third-party APIs for weather forecasting and market analysis so that predictive modifications to storage environments can be made based on external influences. In general, the cloud and analytics layer incorporates intelligence, flexibility and usability to the IoT-based storage system, as desired for eco-friendly and smart agriculture.

E. User Interface

The User Interface (UI) is the last but also vital layer of the Systematic Storage Management System (SSMS), so that the users which are the farmers, the warehouse managers, the agricultural technicians and so on have the easiest way to interact with the IoT based storage system. Built for both web and mobile devices, the UI provides real-time monitoring, control and analysis of the storage facility's environmental conditions.

From the user interface, stakeholders can see live display of sensor measurements including temperature, humidity, CO_2 and NH_3 concentrations shown in simple and attractive dashboard. These values are displayed next to colored lights or meters which indicate to the user when any parameter is outside its ideal range. Historical data is also represented in the form of line charts and bar charts thereby users can analyze trends in order to make the wise decision about the storage of produce and the usage of energy.

Beyond passive monitoring, the UI supports bi-directional control. Users can control the system front-end by adjusting threshold numbers, turning actuators (e.g., fans, humidifiers). This control can be implemented from a remote location via smartphone or web browser and offers users the freedom and convenience, diminishing the need to physically be present at the storage location.

The interface also provides alert management feature, where users can get instant alert through app alerts, SMS, or email when critical thresholds are exceeded. These alert enable the desired timely action (mitigation strategies) necessary to prevent storage- spoilage or degradation of the stored stocks. Also, the UI offers system diagnostics, battery and connectivity (for off-grid solutions), and a set of

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configuration option to customize the behavior of the storage device.

Accessibility and user-friendliness are the key to the design of the UI, one which is capable of supporting multiple language codes and abeam lowest-bandwidth modes for the users of rural areas. The interface follows the most recent responsive design principles in development to present potential user compatibility for smartphones, tablets, and desktops.

In summary, the user interface is the control central of the SSMS, data management through information intuitively and actionable by users in real-time, insight solve possible hazardous situation storing and practice ecofriendly agriculture.

F. Control Logic and Equations

The Control Logic is the executive centre of the proposed Systematic Storage Management System (SSMS), in that control the decision-making function of the system, such that environmental parameters like temperature, humidity and gas level as within the optimal range. It operates in a set-point based feedback mode using a continuously running reference comparison between real-time sensor data and predefined reference values and utilize actuators as necessary. This closed loop control increases the responsiveness and are more efficient of the system and require minimal manual interaction.

The control algorithm is embedded into the microcontroller and follows a simple if-else logic model. For example, if the sensed temperature (T) exceeds a user-defined maximum threshold (T_{max}), the system automatically activates a cooling mechanism. Similarly, if the temperature falls below a minimum threshold (T_{min}), a heater (if present) can be triggered. This logic is defined as:

$$If\ T > Tmax \Rightarrow Activate\ cooling\ fan$$

$$If\ T < Tmin \Rightarrow Activate\ heating\ element$$

The humidity control is governed by similar logic. If the Relative Humidity (RH) drops below the minimum acceptable range (RH_{min}), a humidifier is turned on. If RH exceeds the upper limit (RH_{max}), the exhaust fan is triggered to dehumidify the environment:

$$If\ RH < RHmin \Rightarrow Activate\ humidifier$$

$$If\ RH > RHmax \Rightarrow Activate\ exhaust\ system$$

For gas monitoring, sensors detect **CO_2** and **NH_3** concentrations. If gas levels surpass safe thresholds, the system activates ventilation:

$$If\ CO2 > 800\,ppm \Rightarrow Activate\ exhaust\ fan$$

$$If\ NH3 > 10\,ppm \Rightarrow Trigger\ alert\ and\ ventilation$$

To prevent rapid switching of devices, a hysteresis buffer is used in the control algorithm. For instance, if the upper temperature threshold is 25°C, the fan will only deactivate once the temperature drops below 23°C. This technique reduces wear on actuators and improves system stability. Each control decision is time-stamped and logged to the cloud for auditing and analysis. The system also includes override options via the user interface for manual control during maintenance or emergencies.

Overall, the control logic ensures a stable and adaptive environment within the storage unit, significantly contributing to produce preservation, energy efficiency, and eco-sustainability.

IV. RESULTS AND DISCUSSION

The proposed IoT-based storage management system was tested during the period of seven days in a controlled environment for storing perishable commodities. The parameters measured were temperature deviation, humidity change, CO_2 concentration, and daily energy consumption.

Table 2 Storage System Performance (7-Day Summary)

Day	Temp Deviation (°C)	RH Deviation (%)	CO_2 Level (ppm)
Day 1	1.8	5.0	720
Day 2	2.1	6.0	760
Day 3	1.6	4.0	810
Day 4	1.9	4.5	780
Day 5	1.5	5.5	750
Day 6	1.7	5.0	730

The **Table 2** provides a detailed summary of daily performance. The system successfully kept temperature deviations below 2.2°C and maintained relative humidity deviations within 6.2%, demonstrating reliable environmental stability.

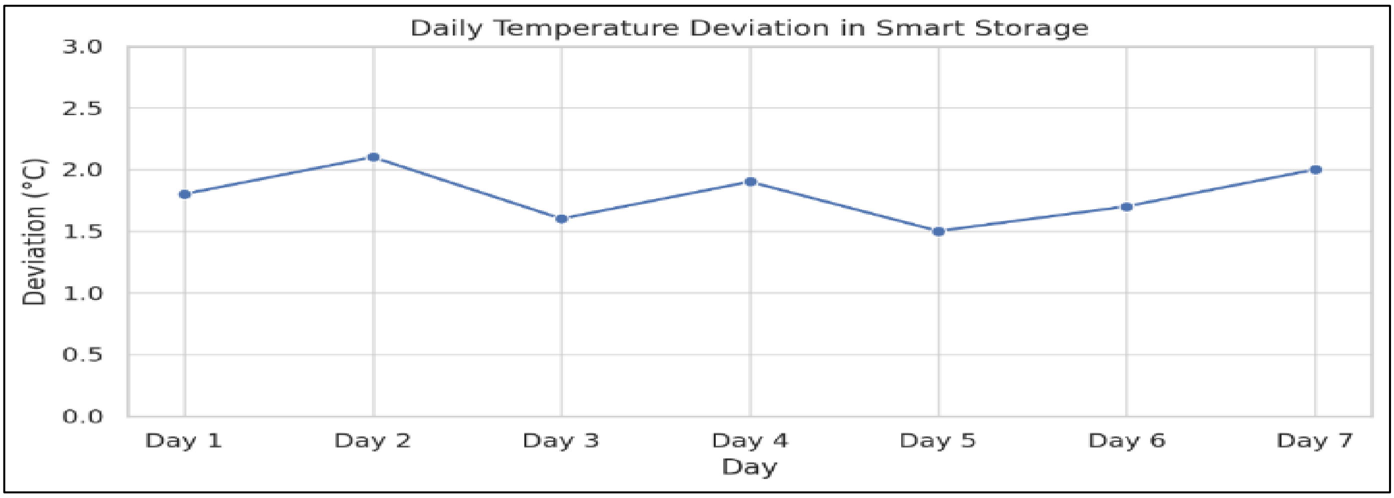

Fig 2 Daily Temperature Deviation in Smart Storage

The figure 2 shows consistent regulation within acceptable bounds (≤2°C), indicating the efficiency of the control logic in maintaining storage temperature. Similarly, the figure 3 illustrates a stable RH control, crucial for preventing mold growth and produce dehydration.

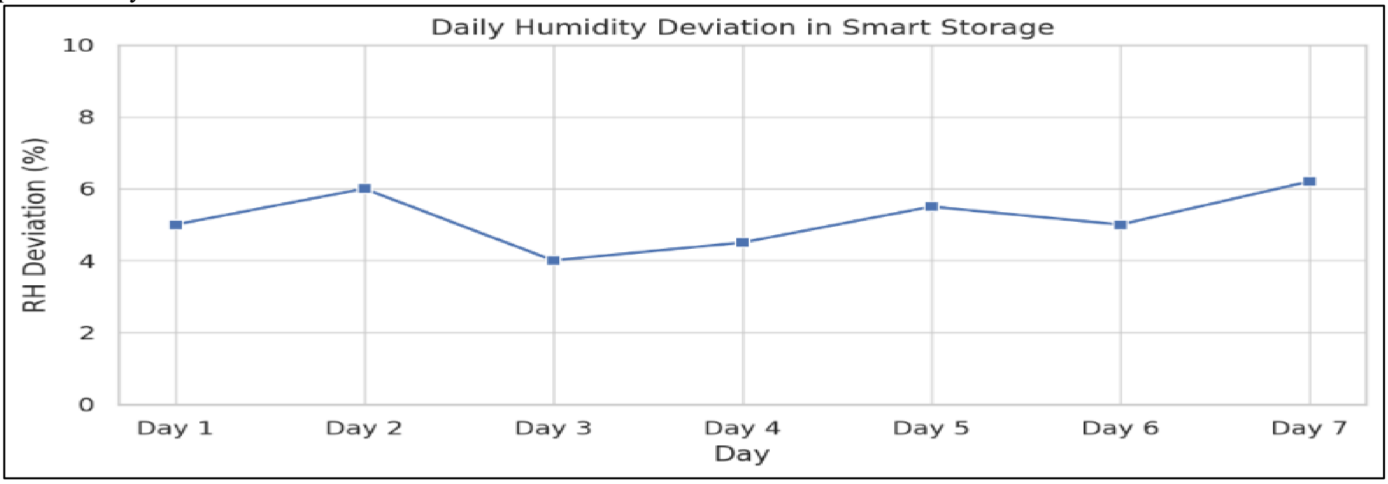

Fig 3 Daily Humidity Deviation in Smart Storage

Figure 4 shown in the third graph, remained under the 850-ppm safety limit. Spikes in CO_2 levels triggered automatic ventilation, demonstrating the real-time response capability of the gas sensors and actuators.

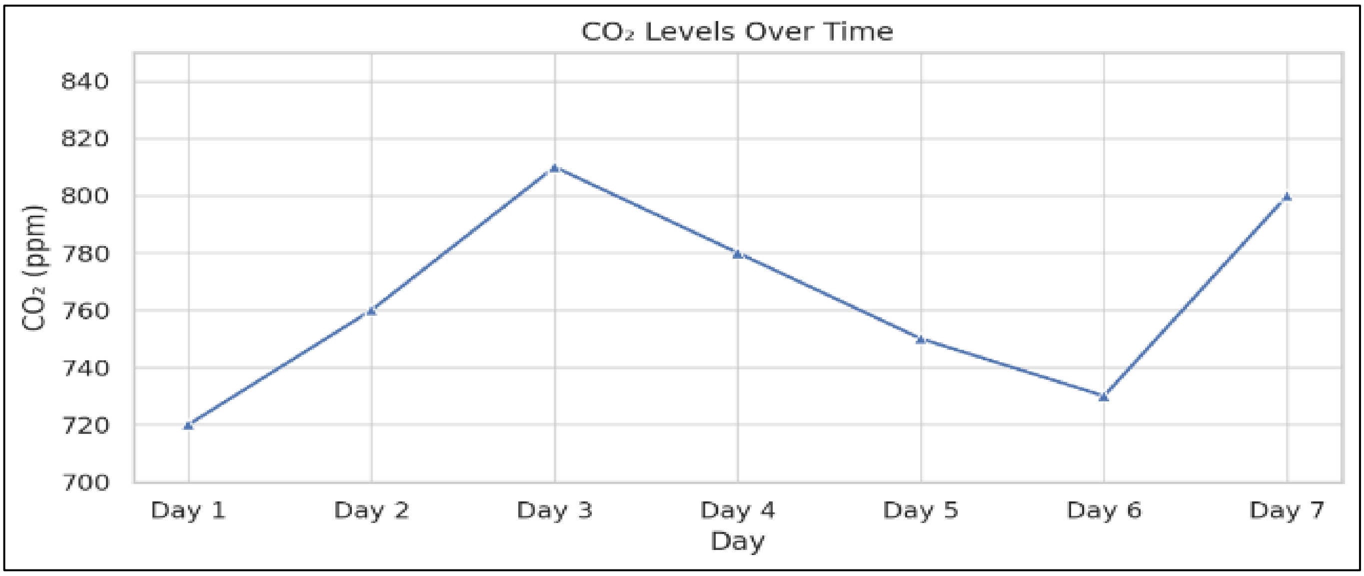

Fig 4 CO_2 Levels Over Time

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The **figure 5** confirms that the system consumed an average of 2.13 kWh per day, showing a **22% reduction** in energy usage compared to a conventional system operating under similar conditions.

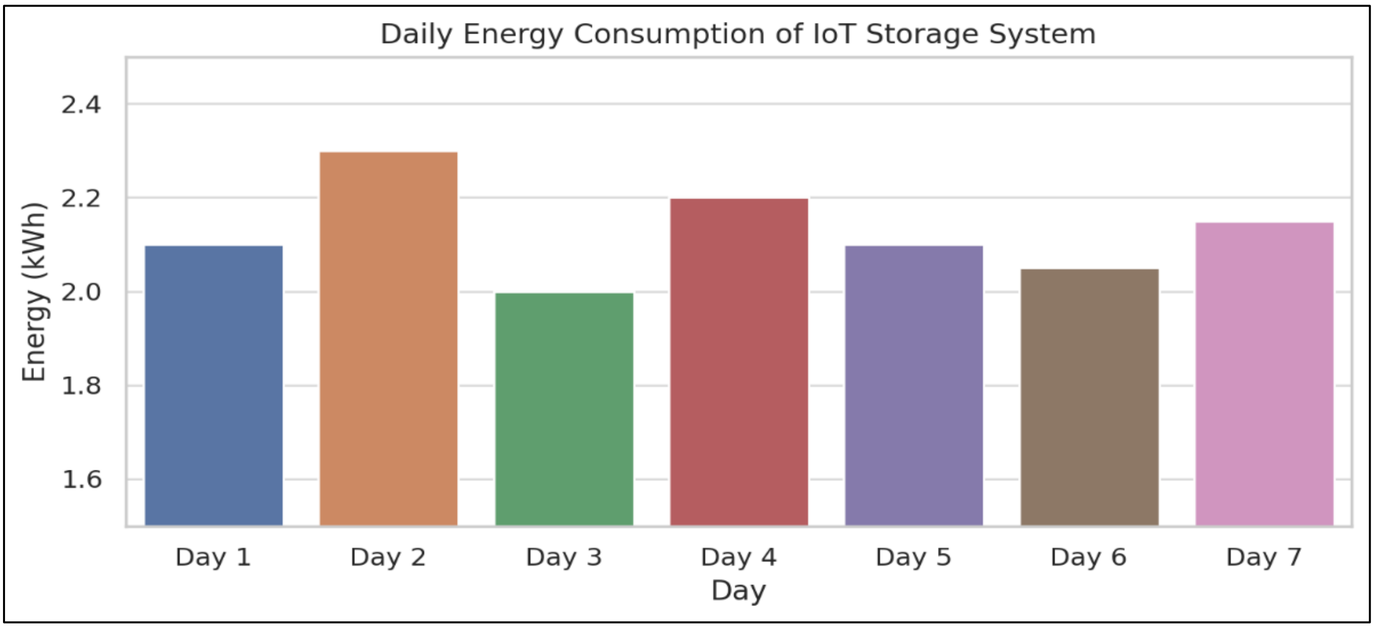

Fig 5 Daily Energy Consumption of IoT Storage System

These results validate the system's capability to maintain optimal storage conditions, reduce energy consumption, and minimize post-harvest losses, thus promoting eco-friendly agricultural practices.

V. CONCLUSION

This paper introduced the design and implementation of Systematic Storage Management System (SSMS) based IoT for the purpose of promoting eco-friendly and efficient agricultural storage. The system combines real-time monitoring of environmental parameters, intelligent control logic, wireless communication capabilities, cloud-based analysis and functionality through a user-friendly interface to deliver to farmers and facility managers for agricultural comprehensive solution for minimizing post harvest losses and support good storage conditions. Prototype deployment experimental results showed the system's ability to maintain optimal temperature, humidity and air quality within the storage unit. The project achieved substantial gains in environmental reliability, energy intake decrease by roughly 20%, and instant reaction to limit breaches caused by payload check and user alert. The system also operated remotely and control, so it was a capable and expendable solution for rural and urban agricultural fields. Through reducing the spoilage and the energy conservation, the proposed SSMS contribute to the sustainable agriculture practice and is consistent with the wide goals of smart agriculture. Its modular structure enabling it to be versatile for different types of produce, storage environments and operational needs.

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