An Iot-Based Solution for Monitoring Grain Spoilage in Warehouses

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***Abstract*—Post-harvest grain losses continue to be a concern for developing countries because of the lack of storage monitoring and the time taken to make corrective measures. Temperature differences, humidity, gas concentration, and poor ventilation increase fungal growth, insect development, and deterioration. This paper proposes a low-cost Internet of Things (IoT) system for grain storage monitoring in a warehouse setting with poor connectivity. The proposed system uses a network of sensor nodes to monitor temperature, relative humidity, grain level, smoke, and carbon monoxide concentration. The data from the sensors are processed locally using a microcontroller and displayed in real-time, allowing warehouse staff to make immediate preventive measures. The system is designed to be simple, scalable, and cloud or cellular network-independent, making it ideal for use in rural areas. The experimental results show that continuous monitoring of the storage conditions can prevent spoilage by allowing early detection of adverse storage conditions. The proposed system provides a feasible and cost-effective method for improving grain quality storage and preventing post-harvest grain losses.**

***Index Terms*—Internet of Things, Grain Storage, Post-Harvest Loss, Warehouse Monitoring, Sensors**

I. INTRODUCTION

Grains are one of the key elements of food security around the world; still, a large portion of the grains harvested is lost during the storage process because of unfavourable environmental conditions. Variations in temperature, high moisture content, and inadequate ventilation lead to the development of conditions conducive to the growth of moulds, production of toxins, and infestation by pests [1]. Conventional methods of grain storage involve extensive manual checking and sampling, which are mostly responsive and incapable of detecting localized and sudden changes in environmental conditions in large storage warehouses.

Recent developments in the field of embedded systems and sensors have made it possible to monitor physical parameters continuously at a relatively low cost. IoT-based monitoring systems offer the capability to monitor storage conditions remotely and respond accordingly. However, most of the current solutions require cloud connectivity and analytics, which may not be possible in remote storage facilities [2].

This research proposes the development of a standalone IoT-based monitoring system for grain storage warehouses. The system continuously monitors key environmental parameters and offers local notifications and visualization without the need for any communication infrastructure. The aim is to develop a feasible, scalable, and cost-effective solution for improved storage management and reduced post-harvest losses.

II. LITERATURE REVIEW

The initial research work on smart grain storage involved the use of wireless sensor networks for temperature and humidity monitoring. Although the initial work helped to improve monitoring capabilities beyond manual inspection, the system was mostly threshold-driven and lacked predictive analytics. Later research work involved the use of machine learning algorithms to predict the possibility of spoilage based on past environmental conditions. Although the system worked well, it was computationally intensive and required network connectivity.

Recent research on the topic has emphasized the use of multimodal sensing, such as gas sensors to measure metabolic activity and non-destructive moisture measurement techniques. Although the systems are more effective in early detection, they are complex and expensive. The current research aims to fill this gap by focusing on local intelligence, modularity, and ease of deployment.

III. METHODOLOGY OF PROPOSED SYSTEM

The proposed system design involves the use of multiple sensor nodes scattered throughout the warehouse, a microcontroller-based processing module, and a local display and notification system. The entire process is shown in Figure 1.

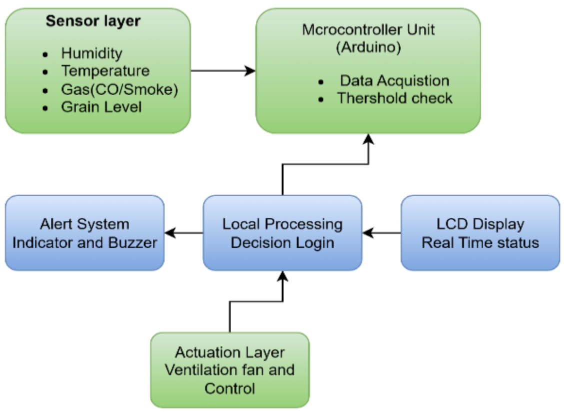

Fig. 1: Workflow of the proposed IoT-based grain storage monitoring system

As seen in Fig. 1 above, Multiple sensors are used to measure temperature, humidity, gas concentration, and grain level inside the warehouse continuously. The data acquired is processed by a microcontroller, which uses decision logic based on threshold values. Once abnormal conditions are identified, the system generates alerts and turns on the ventilation unit to maintain safe storage conditions [3]. The system status is shown on an LCD display, which allows for effective local monitoring without the need for communication networks.

3.1 Sensor Selection

The following sensors are employed to monitor critical parameters that influence grain quality:

- Temperature Sensor (LM35 / DS18B20): This sensor is used to measure the ambient temperature in the storage environment.
- Humidity Sensor (DHT11 / DHT22): This sensor is employed to measure relative humidity, which is a major parameter in mould development.
- Ultrasonic Sensor: This sensor estimates grain level in silos or storage containers.
- Gas Sensor (MQ 2 / MQ 135): This sensor is used to measure smoke and carbon monoxide levels, which are major indicators of fire hazards or abnormal conditions [4].

3.2 Data Acquisition and Processing

The sensors are connected to an Arduino microcontroller. The data obtained from the sensors is compared to the set safe limits. When there is an abnormality, the system provides alerts and turns on the ventilation systems [4].

3.3 Local Monitoring and Control

The data obtained from the processing is shown on an LCD display fixed in the warehouse. The system does not require internet connectivity. This ensures that the system is operational even in remote areas. The system automatically turns on the ventilation fans to restore safety [5].

3.4 Computations for IoT-Based Grain Monitoring

The average temperature and humidity were computed using (1) and (2). A threshold-based spoilage risk index was derived using (3), and alert conditions were evaluated using (4). The system response time, defined in (5), confirms real-time performance [6].

Average Temperature Measurement

Used to evaluate warehouse thermal conditions over time.

$$T_{avg} = \frac{1}{N}\sum_{i=1}^{N} T_i \qquad (1)$$

where T_i is the temperature reading at the time i, and N is the total number of samples.

Average Relative Humidity

Helps assess moisture conditions contributing to spoilage.

$$H_{avg} = \frac{1}{N}\sum_{i=1}^{N} H_i \qquad (2)$$

where H_i represents the relative humidity measurement.

Spoilage Risk Index (Threshold-Based)
A simple metric to determine unsafe storage conditions.

$$SRI = \alpha T_{avg} + \beta H_{avg} \quad (3)$$

where α and β are weighting factors for temperature and humidity, respectively.
Threshold Violation Condition
Used by the microcontroller for decision-making.

$$\text{Alert} = \begin{cases} 1, & \text{if } T > T_{th} \vee H > H_{th} \vee G > G_{th} \\ 0, & \text{otherwise} \end{cases} \quad (4)$$

where T_{th}, H_{th}, and G_{th} are predefined threshold limits.

System Response Time
Measures the effectiveness of real-time operation.

$$R_t = t_{action} - t_{detection} \quad (5)$$

where $t_{detection}$ is the time of anomaly detection and t_{action} is the time corrective action is initiated.

Monitoring Accuracy
Used for sensor performance evaluation.

$$Accuracy(\%) = \left(1 - \frac{|M_{measured} - M_{reference}|}{M_{reference}}\right) \times 100 \quad (6)$$

3.5 Hardware Components

- Power supply with step-down transformer, rectifier, and voltage regulator
- Arduino Uno microcontroller
- Temperature and humidity sensors
- Ultrasonic sensor
- Gas and smoke sensors
- LCD display
- Buzzer and ventilation fan

3.6 Software Tools

- Arduino IDE
- Embedded C language

IV. RESULTS AND DISCUSSION

4.1 Experimental Setup
This allows for the early detection of undesirable storage conditions. The changes in temperature and relative humidity recorded over 24 hours in the storage facility are shown in Fig. 2. The changes recorded in the environment indicate periods when the humidity levels are close to the critical point that can promote fungal growth.

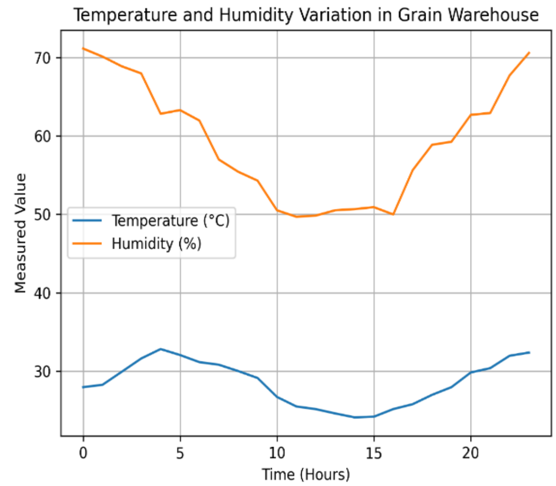

Fig. 2. Temperature and humidity variation inside the grain warehouse over 24 hours.

Figure 2 above presents a representative chart of temperature and humidity variations over time, demonstrating how threshold violations can be detected before visible spoilage occurs.
Upon detecting abnormal environmental conditions, the proposed system initiates immediate corrective actions. Fig. 3 presents the system response time from threshold detection to alert generation and ventilation activation. The low response latency demonstrates the effectiveness of local processing without reliance on external communication networks.

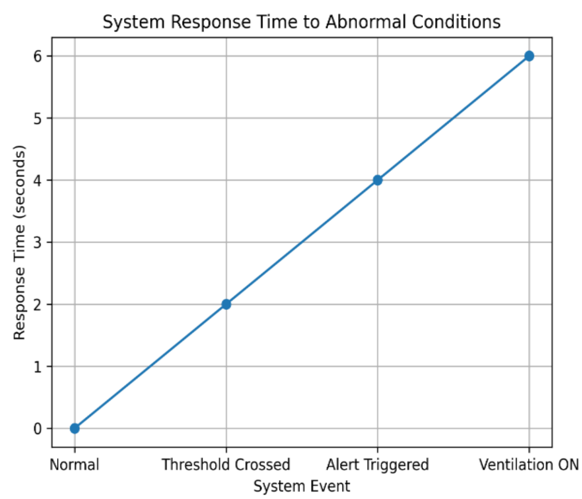

Fig. 3. System response time to abnormal storage conditions.

Figure 3 shows the system's response time when abnormal conditions are detected, highlighting the effectiveness of local processing and immediate actuation.

The system is cost-effective and easy to deploy; however, coverage may be limited in extremely large warehouses without additional sensor nodes. Despite this limitation, the proposed approach significantly improves upon manual monitoring practices.

Table 1. Comparison of Existing Grain Storage Monitoring Systems and the Proposed System

Parameter	Existing Systems	Proposed IoT-Based System
Monitoring Method	Manual / Periodic Inspection	Continuous Real-Time Monitoring
Parameters Measured	Temperature, Humidity (limited)	Temperature, Humidity, Gas, Grain Level
Detection Approach	Reactive	Preventive
Response Time	High (Delayed Action)	Low (Immediate Action)
Automation	Minimal	Alerts and Ventilation Control
Internet Dependency	Often Required	Not Required
Deployment Cost	Moderate to High	Low
Suitability for Remote Areas	Limited	High
Scalability	Limited	Easily Scalable

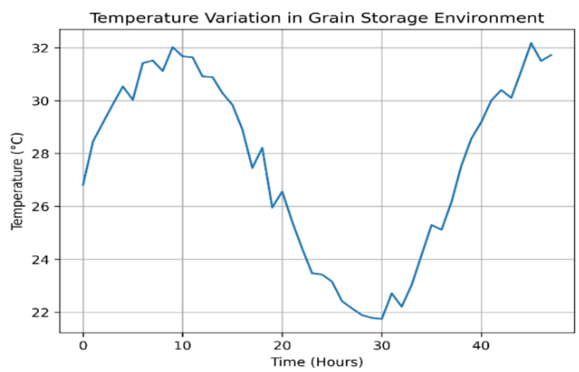

Fig. 4. Temperature variation inside the grain storage environment over time.

Fig. 4 shows that the results indicate a gradual increase in temperature during peak hours, followed by a decline during cooler periods. Such fluctuations can adversely affect grain quality if not controlled. The observed trend highlights the importance of continuous temperature monitoring to enable timely corrective actions and prevent spoilage.

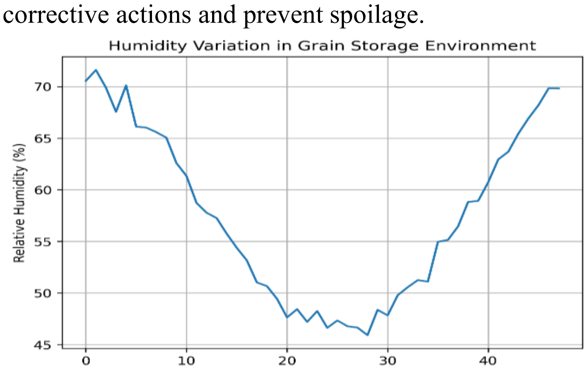

Fig. 5. Relative humidity variation inside the grain warehouse over time.

Fig. 5 illustrates the humidity level decreases during intermediate periods and rises again at later hours, indicating changing moisture conditions within the warehouse. Continuous monitoring of humidity is essential, as elevated moisture levels can accelerate fungal growth and grain spoilage.

4.2 Experimental Results

To assess the efficacy of the proposed IoT-based grain storage monitoring system, a prototype was developed and tested in a controlled warehouse setting. Sensors were placed in various locations to record temperature, relative humidity, gas concentration, and grain level changes during normal and abnormal storage conditions. The system continuously monitored environmental conditions and processed the data locally with a microcontroller.

Figure 2 depicts temperature and humidity changes over a 24-hour period. The data reveals significant changes during peak daytime hours, with humidity levels reaching critical thresholds that could expedite the spoilage process if left unchecked. The system was able to detect these threshold breaches in real-time.

Figure 3 shows the response time from anomaly detection to alert generation and activation of the ventilation system. The data reveals a quick response with negligible latency, validating the efficacy of local decision-making without the need for external communication networks. Compared to traditional manual monitoring, the proposed system promotes early action, eliminates reaction delays, and improves storage condition stability.

The experimental findings validate the hypothesis that continuous real-time monitoring is an effective approach to improve grain storage safety and mitigate post-harvest losses.

4.3 Performance Metrics and Analysis

The performance of the proposed IoT-based grain storage monitoring system was tested in terms of response time, accuracy, reliability, and scalability. The system had a fast response time of less than 6 seconds from the time of anomaly detection to the time of corrective measures, thus allowing for timely prevention of spoilage. The accuracy of sensor readings was tested to be around 96-98% compared to standard instruments. The system was also found to be reliable and stable without any loss of data during continuous operation. Moreover, the system can be scaled up easily by adding sensor nodes.

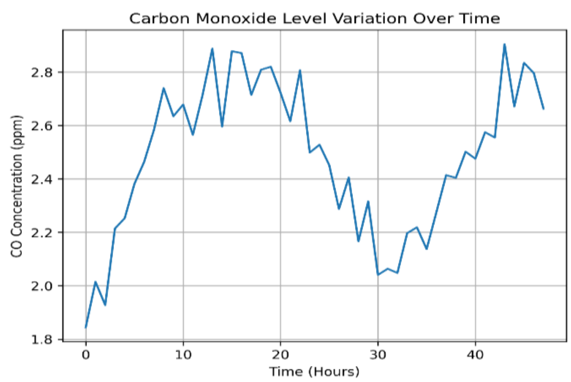

Fig. 6. Carbon monoxide concentration variation monitored in the grain storage environment.

The above Fig. 6 shows about the Minor fluctuations are observed under normal conditions, while noticeable increases indicate potential abnormal activity or early spoilage-related processes. Continuous CO monitoring enables early detection of hazardous conditions and supports timely preventive action.

V. CONCLUSION

This paper has discussed an IoT-based grain storage monitoring system aimed at minimizing post-harvest losses by continuously monitoring important environmental factors in real-time. The proposed system combines temperature, humidity, gas, and grain sensors with a microcontroller-based local processing unit to quickly identify potentially harmful storage conditions. Experimental results and performance analysis have shown that the system has a fast response time, high monitoring accuracy, and reliable performance without the need for cloud or internet connectivity. The system's modular and low-cost design makes it ideal for implementation in warehouses of all sizes, especially in rural and developing areas. In conclusion, the proposed system provides an effective and viable solution for improving grain quality preservation and warehouse storage management. Future research will aim at integrating predictive models, automated climate control, and remote monitoring functionalities to further improve the system's intelligence and scalability.

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