SMART GRAIN STORAGE SYSTEM

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Abstract: Grain storage is a critical process in agriculture, as improper storage conditions lead to significant post-harvest losses due to moisture, temperature variation, pests, and fungal growth. This study proposes a Smart Grain Storage System that uses IoT-based sensors to continuously monitor environmental parameters such as temperature, humidity, and gas levels inside storage units. The collected data is processed using a microcontroller and transmitted to a cloud platform for real-time monitoring and alerts. If abnormal conditions are detected, automatic control mechanisms such as ventilation fans and moisture control systems are activated. The proposed system aims to reduce grain spoilage, maintain quality, and increase storage efficiency. Based on the review of multiple research studies, the system offers a cost-effective and scalable solution for farmers and warehouses. This approach helps in minimizing losses, improving food security, and supporting sustainable agricultural practices.

Index Terms - Smart grain storage, IoT, WSN, AI, post-harvest loss, predictive monitoring, automation

I. INTRODUCTION

Grain storage is essential in the food security of the world for the availability, stability, and safety of staple cereals. Post-harvest losses are a perennial problem with a study showing the spoilage of 10–25% of the stored grain every year due to incorrect handling, poor supervision, and environmental instability. Traditional storage relies mainly on manual inspection and serial interventions, and cannot effectively identify early spoilage indicators such as temperature gain, humidity change, fungal development, pests and so on. This often results in a heavy decline in quality when corrective actions are delayed. IoT-based sensors, AI-powered analytics, wireless communication, automated ventilation systems and other intelligent technologies are changing the face of the agricultural storage facilities. Despite great advances, serious challenges still exist, such as the expensive cost for industrial-grade systems, lack of access to rural areas, lack of commonly used datasets, and digital infrastructure are poorly maintained. This review paper aims to give a comprehensive overview concerning major problems and current technical developments in grain storage as well as what the future trends are in the field that affect the future of grain storage systems. The objective here is to summarize the current state of the art for grain storage. Recent advancements via cloud-based platforms and mobile applications are optimizing real-time monitoring and remote management of storage facilities, which is especially common in large-scale operations.

II. LITERATURE SURVEY

In paper [1] IoT-based grain monitoring system using DHT11, MQ135, MQ2, and PIR sensors with NodeMCU and Blynk app to monitor temperature, humidity, gas, and motion in storage. It helps reduce post-harvest losses and provides real-time alerts for better grain management. However, it is prototype-based, depends on internet connectivity and sensor accuracy, and lacks security and large-scale validation.

In paper [2] An IoT-based granary management system using PIR, DHT22, and fire sensors with Arduino and Raspberry Pi to monitor environmental conditions and control actuators like fans and alarms. It improves grain safety and enables remote monitoring. However, it is tested only at prototype level and lacks insect detection, security mechanisms, and large-scale testing.

In paper [3] A smart agriculture storage system using Arduino, relay modules, and HC-05 Bluetooth to control AC, fan, and light in a storage room via smartphone. It helps farmers protect crops from rain and temporary storage issues. However, it has higher initial cost, requires continuous power supply, and large-scale deployment increases complexity.

In paper [4] IoT-based grain quality monitoring system using DHT11, LM35, MQ3, and ultrasonic sensors with NodeMCU and Firebase cloud. It also uses an ARIMA model to predict humidity and help determine grain shelf life. However, the system has high cost, internet dependency, and issues related to sensor reliability and standardization.

In paper [5] This review paper discusses IoT-based grain storage systems that use sensors and cloud monitoring to reduce post-harvest losses. These systems improve storage efficiency through real-time monitoring and predictive analytics. However, high cost, internet dependency, sensor reliability, and lack of awareness limit practical adoption.

In paper [6] IoT-based smart warehouse monitoring system using DHT11, MQ2, PIR, and vibration sensors connected to ESP32 and Blynk app. It monitors temperature, humidity, gas, and motion and sends alerts when conditions become unsafe. However, the system requires continuous internet and power supply and increases maintenance complexity.

In paper [7] Smart grain stock monitoring system using sensors like DHT22, LDR, MQ-2, moisture, and IR with NodeMCU and Adafruit IO cloud via MQTT. It helps detect abnormal storage conditions and reduce grain loss. However, it is prototype-based and lacks security, cost analysis, and long-term performance evaluation.

In paper [8] Arduino-based grain storage monitoring system using temperature, humidity, light, rain, and fire sensors with automatic fan control. Data is transmitted through Bluetooth to a mobile device for monitoring. However, Bluetooth has limited range and the system lacks internet connectivity, scalability, and security features.

In paper [9] IoT-based grain warehouse monitoring system using multiple sensors connected to a PIC microcontroller and GSM module to send data to the cloud and SMS alerts. It helps detect unsafe storage conditions and reduce grain wastage. However, it increases hardware cost and depends on network availability and power supply.

In paper [10] Smart grain silo monitoring system using sensors for temperature, humidity, CO_2, and insect detection with Arduino and Blynk app. It automatically controls storage conditions and supports remote monitoring. However, testing was done without actual grain storage and the system depends on reliable power and internet connectivity.

From the literature review, it is observed that many IoT-based grain storage monitoring systems have been developed to monitor environmental parameters such as temperature, humidity, gas levels, and motion. However, most of these systems are prototype-based and lack large-scale real-time implementation. Many existing solutions also depend heavily on continuous internet connectivity and power supply, and they often lack proper security mechanisms and long-term performance evaluation. Therefore, there is a need to develop a more reliable, cost-effective, and scalable smart grain storage system that can efficiently monitor storage conditions and reduce post-harvest losses.

III. HARDWARE AND SOFTWARE DESCRIPTION

The hardware design of the proposed smart grain storage system is developed to achieve reliable monitoring of storage conditions, accurate sensing of environmental parameters such as temperature, humidity, gas levels, and moisture, and efficient control of ventilation to maintain grain quality.

3.1 ESP32

The ESP32 shown in fig 1, is a powerful microcontroller with built-in Wi-Fi and Bluetooth connectivity. It is widely used in IoT applications to collect data from sensors and send it to cloud platforms or mobile applications. In a smart grain storage system, the ESP32 processes data from sensors such as temperature, humidity, and gas sensors and enables real-time monitoring and control of storage conditions.

Fig 1. ESP32

3.2 16*2 LCD I2C Display

The 16×2 LCD I2C display shown in fig 2, is an alphanumeric display module that can show 16 characters in 2 rows. It uses the I2C communication protocol, which reduces the number of pins required to connect with a microcontroller such as ESP32 or Arduino. This display is commonly used to show sensor readings, system status, and messages. In a smart grain storage system, it can display temperature, humidity, gas levels, and other monitoring information in real time.

Fig 2. 16*2 LCD I2C Display

3.3 Relay Module

A relay module is an electronic switching device that allows a low-power microcontroller (such as ESP32 or Arduino) to control high-voltage or high-current devices like fans, motors, or lights. It works as an electrically operated switch that turns devices ON or OFF based on signals from the controller. In a smart grain storage system, the relay module is used to automatically control devices such as ventilation fans or alarms when abnormal conditions like high temperature or humidity are detected, helping maintain proper storage conditions for grains.
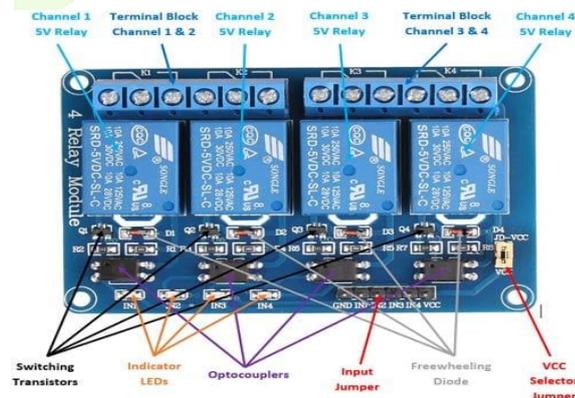

Fig 3. Relay Module

3.4 MQ135 Gas Sensor

The MQ135 Gas Sensor shown in fig 4, is used to detect harmful gases such as ammonia, benzene, smoke, and carbon dioxide in the air. In grain storage systems, it helps monitor gas levels produced by spoiled grains or poor storage conditions.

Fig 4. MQ135 Gas Sensor

3.5 DHT22 Temperature and Humidity Sensor

The DHT11 shown in fig 5, is a digital sensor used to measure temperature and humidity. It helps monitor environmental conditions inside the grain storage area to prevent spoilage caused by high humidity or temperature. It provides reliable environmental data and communicates with microcontrollers such as Arduino, ESP32, or NodeMCU through a single digital pin.

Fig 5. DHT22

3.6 Moisture Sensor

The soil moisture sensor shown in fig 6 measures the moisture level in soil or grain. It helps detect excess moisture that can lead to fungal growth and grain damage.
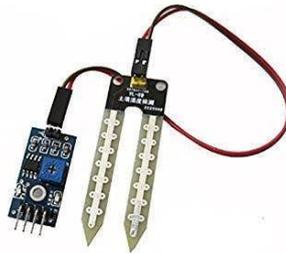

Fig 6. Moisture Sensor

3.7 SW420 Vibration Sensor

The vibration sensor shown in fig 7, detects movement or vibration around the storage unit. It can help identify disturbances, possible pest activity, or external interference in the grain storage area.

Fig 7. SW420 Vibration Sensor

3.8 DC Cooling Fan

The DC cooling fan shown in fig 8, is used to maintain proper air circulation inside the storage unit. It helps reduce temperature and humidity levels, thereby protecting the grains from spoilage.

Fig 8. DC Cooling Fan

3.9 UV Light

Ultraviolet (UV) light shown in fig 9, is a type of electromagnetic radiation with a wavelength shorter than visible light. It is commonly used for sterilization and disinfection because it can destroy microorganisms such as bacteria, fungi, and insects.

In a smart grain storage system, UV light can be used to reduce microbial growth and prevent fungal contamination in stored grains. This helps maintain grain quality, extend storage life, and reduce post-harvest losses.

Fig 9. Ultraviolet Light

IV. WORKING OF SMART GRAIN STORAGE SYSTEM

The proposed Smart Grain Storage System is an ESP32 based IoT monitoring and control system developed to reduce post-harvest grain losses. It uses multiple sensors, including a temperature and humidity sensor, moisture sensor, gas sensor, and vibration sensor, to continuously monitor the internal storage conditions. These parameters are critical because high temperature, excess humidity, increased moisture content, harmful gas formation, or unusual vibrations can indicate spoilage, fungal growth, or pest activity.
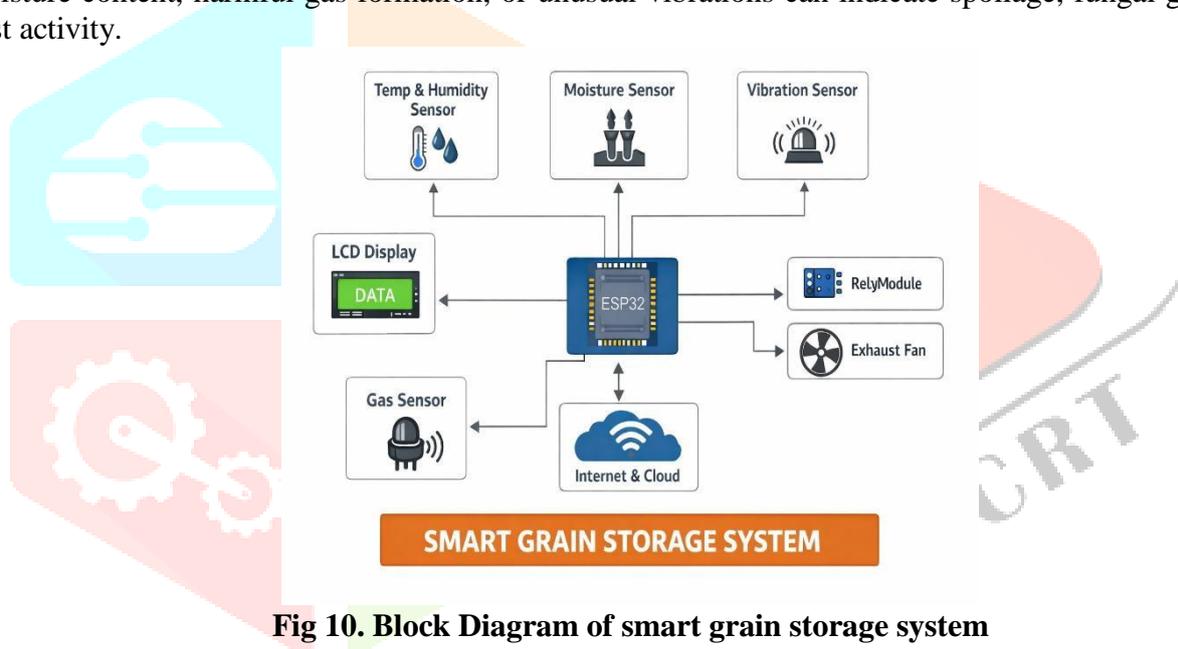

Fig 10. Block Diagram of smart grain storage system

The ESP32 collects and processes all sensor data, compares it with predefined safe threshold values, and automatically controls a relay module when abnormal conditions are detected. The relay activates devices such as an exhaust fan to maintain proper air circulation and stable storage conditions. Real-time readings and system status are displayed on an LCD screen for easy on-site monitoring.

In addition, the system logs all sensor data with timestamps and stores it in an Excel sheet through WiFi connectivity. Every 30 minutes, the recorded data is compiled into a PDF report and automatically sent to a registered email address. This ensures proper documentation, remote monitoring, and timely action, making the system efficient and suitable for small- and medium-scale grain storage facilities.

4.1 Flowchart of Smart Grain Storage System

The flow of Smart grain storage system which is shown in the fig 2, starts by placing grain in the storage container where sensors continuously monitor temperature, moisture, gas, and vibration. The sensor data is displayed on the screen and recorded in an Excel sheet every few seconds. If the temperature becomes high, the system automatically turns the fan ON to control it. If vibration is detected, an alert email is sent, and the monitoring process continues with periodic data storage.
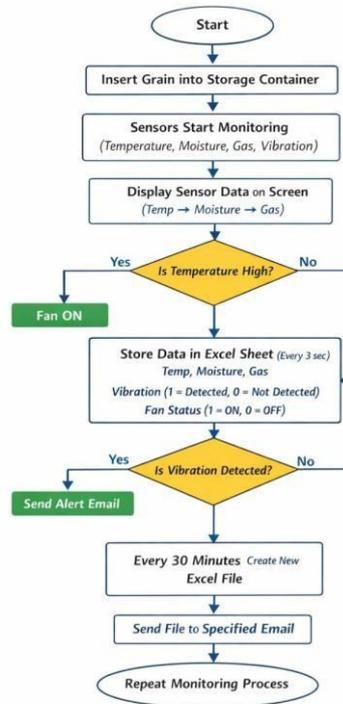
Smart Grain Storage System Workflow

Start

Insert Grain into Storage Container

Sensors Start Monitoring
(Temperature, Moisture, Gas, Vibration)

Display Sensor Data on Screen
(Temp → Moisture → Gas)

Is Temperature High? — Yes → Fan ON / No

Store Data in Excel Sheet *(Every 3 sec)*
Temp, Moisture, Gas
Vibration (1 = Detected, 0 = Not Detected)
Fan Status (1 = ON, 0 = OFF)

Is Vibration Detected? — Yes → Send Alert Email / No

Every 30 Minutes *Create New* Excel File

Send File to Specified Email

Repeat Monitoring Process

Fig 11. Flow chart of Smart Grain Storage System

V. RESULTS AND DISCUSSION

In our project, we use a grain storage container equipped with sensors such as temperature, moisture, gas, and vibration sensors. After inserting the grain, the sensors detect the environmental conditions and display the data on the screen one by one, such as temperature, moisture, and gas levels. If the temperature exceeds the set limit, the fan automatically turns on to control the temperature.

Fig 12. System Connections and Output Display

The system stores all sensor data in an Excel sheet every 3 seconds, recording values like temperature, moisture, gas, vibration (1 if detected, 0 if not), and fan status. After every 30 minutes, a new file is automatically created and sent to a specified email address, and if vibration is detected, an alert message is also sent to the same email.

Fig 13. Excel-Based Data Recording

VI. CONCLUSION

The Smart Grain Storage System successfully provides a reliable and automated solution to reduce post-harvest losses. By using ESP32 and multiple sensors, the system continuously monitors temperature, humidity, moisture, gas levels, and vibrations to maintain safe storage conditions. Automatic control of fans through a relay module helps in preventing spoilage and maintaining grain quality. Additionally, real-time display, data logging in Excel, and periodic email reports improve monitoring, documentation, management efficiency.

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