**Warewatch: Next-Gen Warehouse Monitoring System Using**

**IoT and Wireless Protocol**

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***Abstract*—In a world where nearly 40% of food is wasted post-harvest due to inadequate storage management, the reliance on traditional monitoring methods poses significant challenges for grain storage. The Warewatch system introduces an innovative IoT-based approach to monitor crucial parameters such as temperature, humidity, and light in real-time, ensuring optimal storage conditions and reducing spoilage. Grains are stored in dedicated slots with real-time tracking, allowing for tailored storage solutions for different grains, including freezing and light control. The system includes a mobile application that provides farmers with an intuitive platform to monitor grain conditions, receive alerts, and access reports. Additionally, the app facilitates real-time market exchange, allowing farmers to access current grain prices and trade directly, ensuring transparency and preventing manipulation of grain quality. This scalable and affordable solution leverages low-cost IoT sensors to ensure accurate grain management, empowering farmers with greater control and trust in the system.**

***Keywords—* *IoT, Warehouse Monitoring, Autonomous Navigation, Real-time Data Analysis, Hazard Detection***

I. Introduction

Grain storage is a critical aspect of global food security, with over 40% of harvested crops lost post-harvest due to improper storage and monitoring conditions. Grain quality is highly sensitive to environmental factors like temperature, humidity, and light, which, when unmanaged, lead to spoilage and economic loss. Traditional storage methods rely heavily on manual monitoring, which is prone to human error and inefficiencies, making it difficult to maintain optimal storage conditions.

Farmers and warehouse operators face significant challenges in ensuring the proper management of stored grains. Current systems often lack real-time tracking capabilities and individualized monitoring, resulting in preventable losses and the manipulation of grain quality. These issues are compounded by the difficulty of accessing transparent market information, further reducing the efficiency of grain management and exchange.

To address these challenges, Warewatch has been developed as an advanced IoT-based monitoring system designed to optimize grain storage conditions and enhance transparency in the grain exchange process. The system leverages low-cost sensors to monitor critical parameters such as temperature, humidity, and light in real-time while providing tailored storage solutions for different types of grains. Through a dedicated mobile application, farmers and warehouse operators can track storage conditions, receive alerts for any deviations, and access real-time grain market prices, enabling direct and transparent grain exchanges. The system also ensures that the stored grains remain unmanipulated, maintaining their original quality and quantity throughout the storage and exchange process.

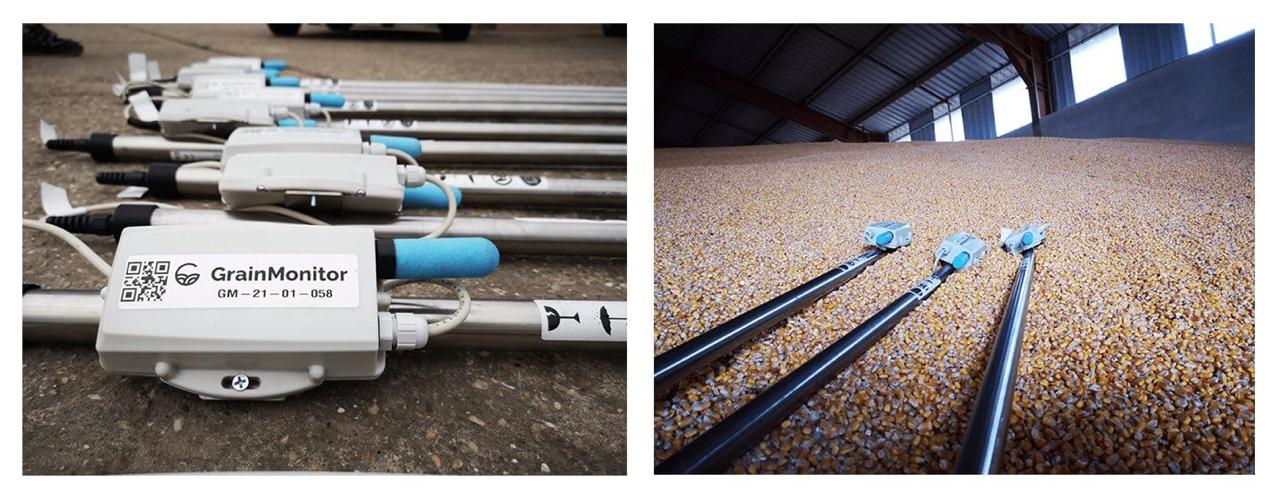
 By integrating IoT technology with real-time monitoring and market access, Warewatch aims to reduce post-harvest losses, improve transparency in grain management, and provide a scalable solution to global food storage challenges.



Fig 1: Types of grain storage monitoring systems.

By harnessing IoT technology, the Warewatch system continuously monitors and analyses environmental conditions in each storage slot, providing instant alerts to ensure optimal grain preservation and enhance storage management efficiency.

The main objectives of the proposed model are:

* To develop a smart IoT-based warehouse monitoring system that tracks real-time environmental parameters like temperature, humidity, and light, ensuring optimal storage conditions and reducing post-harvest losses.
* To provide a user-friendly mobile application for real-time monitoring, alerts, and direct grain trading, ensuring transparency and efficient management of stored grains.

The next section explores the design and components of the IoT-based warehouse system, and Section 3 discusses the implementation of the mobile app and real-time monitoring. Section 4 presents the results, including snapshots of the system in action, and Section 5 concludes with the limitations and future work for scaling the system.

II. Literature Survey

In the last decade, numerous technologies have been developed to improve warehouse management and grain storage monitoring. The literature survey highlights various innovations aimed at optimizing storage conditions, reducing post-harvest losses, and improving operational efficiency. These technologies range from basic temperature and humidity sensors to advanced IoT-based systems capable of real-time monitoring and data analysis. This chapter presents an overview of previous research, identifying the advantages, disadvantages, and methods used in existing systems. It offers an up-to-date understanding of the research area and its practical implications.

In the paper [1], the authors address the inefficiencies of traditional grain storage methods, which rely on manual inspection and are prone to human error. They propose an IoT-based system for continuous monitoring, emphasizing the need for real-time data collection to maintain optimal storage conditions. The study highlights the limitations of existing systems in terms of scalability and automation.

In the paper [2], the authors present an advanced grain storage monitoring system that integrates IoT sensors for tracking temperature and humidity. The system aims to reduce spoilage by providing real-time alerts when storage conditions deviate from the ideal range. The literature survey emphasizes the need for affordable, scalable solutions, especially in regions with limited technological infrastructure.

The paper [3] focuses on using low-cost IoT sensors to monitor environmental factors in warehouses. This study explores the potential of using cloud-based platforms to analyze the collected data, providing actionable insights to improve storage efficiency. The authors also discuss the limitations of wireless communication systems in large-scale warehouses and propose solutions to enhance network reliability.

According to [4],the authors introduce a smart warehouse management system that uses both IoT sensors and AI-based algorithms to predict and prevent spoilage. The proposed system leverages machine learning techniques to analyze historical data and optimize storage conditions for different types of grains. The study shows promising results in reducing post-harvest losses, although the implementation costs remain a challenge for widespread adoption.

In the paper [5] , a mobile application is developed to enable farmers and warehouse managers to monitor storage conditions remotely. The app integrates real-time data from IoT sensors and allows users to track grain quality, receive alerts, and access market prices. The authors emphasize the importance of user-friendly interfaces to ensure wide acceptance of the technology, particularly in rural areas.

The integration of blockchain technology with IoT systems for warehouse management is explored in [6], providing a tamper-proof record of all grain transactions and ensuring transparency. This innovation addresses the common issue of grain manipulation during storage and returns, but the cost of integrating blockchain with IoT remains high for small-scale warehouses.

Another study in the paper [7] focuses on slot-wise storage systems, where grains are stored in dedicated slots based on their specific requirements, such as temperature and humidity. The system uses IoT sensors to monitor each slot individually, ensuring optimal conditions for different types of grains. The authors highlight the system’s effectiveness in reducing spoilage but note that the complexity of managing multiple slots may increase operational costs.

The paper suggests [8], a comprehensive IoT-based system is proposed for real-time market exchange, allowing farmers to access current grain prices and trade grains directly through a mobile application. The study highlights the transparency and efficiency brought by the system, ensuring that farmers are not subjected to unfair pricing or manipulation during grain exchanges.

In the paper [9], the authors propose a scalable and affordable IoT-based monitoring system that utilizes low-cost sensors to track temperature, humidity, and other key parameters in large warehouses. The system shows significant potential in reducing post-harvest losses, but challenges remain in terms of network stability and the integration of advanced data analytics for real-time decision-making.

The authors suggest [10] a system for monitoring food grain storage conditions, specifically focusing on temperature and humidity. They use sensors linked to a PIC microcontroller, which sends data over Ethernet to a VB.NET database. The goal is to enhance storage efficiency and reduce losses by maintaining the quality of grains. The system has shown effective monitoring in experiments, and it could also be applied to fruit storage.

This paper [11]explains about developing an automated system for managing food grain storage. The authors use an Arduino UNO with an HC-05 Bluetooth Module and various sensors to monitor conditions like temperature, humidity, rain, and fire. The system aims to cut down storage losses by 20-30% by providing real-time data for timely actions, such as adjusting ventilation.

[12]The authors suggest a method for monitoring food grain storage by using sensors to check humidity, temperature, and ammonia gas levels. They utilize Arduino circuits to collect data and send it via WiFi for continuous monitoring. The objective is to alert managers to harmful conditions, helping prevent spoilage and reduce economic losses due to food waste in India.

This paper [13] suggests a smart monitoring system for food grain storage using IoT technology. It integrates various sensors (for temperature, humidity, gas, and motion) with Node MCU ESP8266 microcontrollers. The sensor data is sent to the cloud using the Blynk app, allowing for remote monitoring and quick responses to prevent spoilage, with an aim to reduce storage losses by up to 40%.

The authors suggest [14] an IoT system designed to monitor food grain storage conditions in real-time. It checks important factors such as temperature, humidity, and gas levels, transmitting data to the cloud via GSM. This allows for remote monitoring through SMS and mobile apps, helping to decrease food loss and improve storage efficiency, particularly in developing countries.

This paper [15] provides a systematic literature review and bibliometric analysis of warehouse management systems (WMS) focusing on social and environmental sustainability. It identifies the current state of research, highlights the integration of WMS with other systems to enhance sustainability efforts, and discusses the importance of digitalization in improving the environmental and social impacts of warehouse operations.

This paper [16] introduces an IoT-based system for real-time monitoring of food grain storage conditions in warehouses. The system aims to improve food safety and reduce wastage by continuously monitoring temperature, humidity, and pest activity, thereby ensuring optimal storage conditions and timely interventions .

This paper [17] presents an IoT-based smart warehouse monitoring system designed to track various environmental parameters like temperature, humidity, and light intensity. The system leverages sensors and wireless communication to provide real-time data, enhancing decision-making and operational efficiency in warehouses.

This research [18]develops a comprehensive IoT-based monitoring system for warehouses, integrating sensors, data analytics, and cloud computing. The system provides real-time monitoring, predictive maintenance, and enhanced security features, ultimately aiming to improve warehouse management efficiency and reduce operational costs.

The authors suggest [19] a modeling approach for storage grain and environment conditions based on the Two-step Partial Least Squares (TS-PLS) method. This study aims to analyze the relationship between grain storage conditions and environmental factors, contributing to better management practices in agricultural storage

This paper discusses [20] a smart warehouse management system that integrates advanced technologies to improve operational efficiency and optimize inventory management. The system emphasizes the use of IoT, automation, and data analytics to enhance decision-making and streamline warehouse processes.

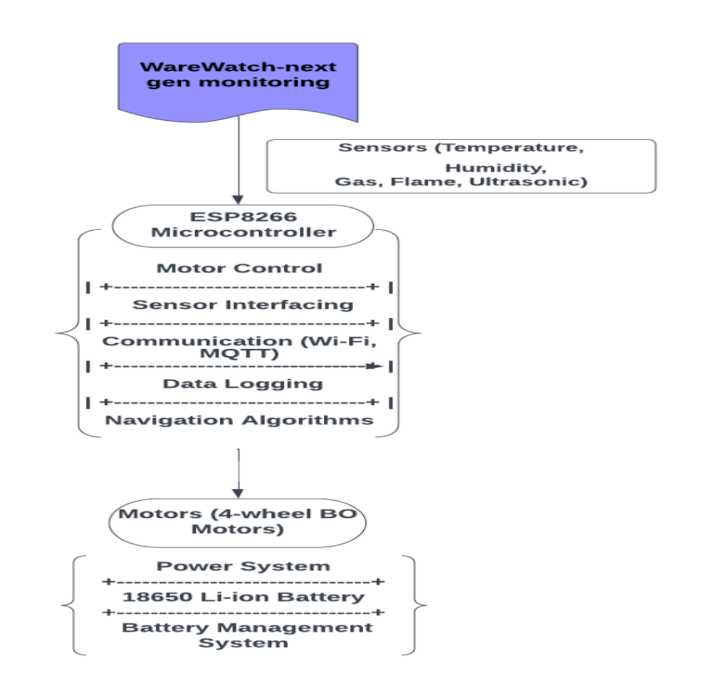
 This research presents [21] the design of a stored grain monitoring system based on Narrowband IoT (NB-IoT). The system aims to ensure the quality of stored grains by continuously monitoring environmental conditions, providing a reliable solution for agricultural storage management.

Fig: Block diagram of Hardware

TABLE I COMPARISON OF DIFFERENT GRAIN STORAGE MONITORING SYSTEMS

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| ***Models*** | ***Objective*** | ***Parameters*** | ***Features*** | ***Drawbacks*** |
| Traditional Manual Monitoring [1] | Manual inspection storage conditions | Human effort | No real-time data relies on manual  checks | Prone to human error, time-consuming |
| Basic IoT System   [2] | Monitor temperature and humidity | Temperature, Humidity | Real-time tracking of basic parameters | Lacks integration with mobile apps, limited data analytics |
| Advanced IoT Monitoring [3] | Comprehensive monitoring of multiple parameters | Temperature, Humidity,  Gas | Real-time tracking, automated alerts | Higher implementation costs |
| Slot-wise Monitoring [4] | Tailored storage for different grain types | Temperature, Humidity, Light | Individualized monitoring per slot | Increased operational complexity |
| IoT with Mobile App  [5] | Remote monitoring and alerts via mobile app | Multiple environmental parameters | Real-time monitoring, alerts, data access through   app | Requires stable internet connectivity |

As shown in Table 1, different types of grain storage monitoring systems provide varying levels of efficiency in managing environmental conditions. However, many existing systems lack comprehensive, real-time monitoring and transparency in grain management. The proposed Warewatch model incorporates advanced IoT-based monitoring, which enables real-time tracking of critical parameters such as temperature, humidity, and gas levels. This system provides instant alerts to users, ensuring immediate response to any deviations from optimal storage conditions. Additionally, the mobile application allows for seamless interaction, enabling users to monitor storage remotely, receive alerts, and access real-time market data, thereby improving storage efficiency and reducing post-harvest losses.

III. METHODOLOGY

The foundation of the Warewatch system lies in the utilization of advanced IoT technologies, primarily relying on sensor integration and data analytics to enhance grain storage management and reduce post-harvest losses. The implementation process involves meticulous planning, covering various stages such as sensor deployment, data acquisition, and real-time monitoring. At its core, the ESP8266 microcontroller plays a pivotal role, overseeing the entire operation due to its compact design and robust connectivity capabilities. By incorporating libraries such as PubSubClient for MQTT communication and OpenCV for data processing, the software can effectively analyze sensor data in real time, ensuring optimal storage conditions and detecting potential hazards in the warehouse environment. This implementation requires not only efficient algorithms for accurate data interpretation but also seamless integration of various sensors to provide comprehensive monitoring, as illustrated in Fig. 2

Figure 2: Block diagram of Hardware

1. *Algorithms for Data Analysis and Monitoring: IoT-Based Warehouse Management*

The Warewatch system employs a comprehensive algorithmic framework to analyze environmental data from multiple IoT sensors, including temperature, humidity, gas, flame, and ultrasonic sensors. This integration ensures optimal storage conditions for various grains through real-time monitoring. The system uses threshold-based detection and statistical analysis techniques, such as Kalman filtering, to maintain accurate readings despite environmental fluctuations.

With a slot-wise storage management approach, the system tailors monitoring to specific grain requirements, minimizing spoilage. Real-time alerts are sent to warehouse managers when parameters deviate from preset thresholds, facilitating timely interventions. Additionally, the system provides access to real-time market prices, allowing users to make informed trading decisions.

A user-friendly mobile application enables stakeholders to monitor conditions, receive alerts, and access market data conveniently. The efficient architecture allows for rapid data processing, enhancing responsiveness and adaptability. By leveraging machine learning, the system continuously learns from historical data, improving its predictive capabilities and ensuring the safety and quality of stored grains.

***Pseudocode for Warewatch System***

**Input:** Sensor Data

**Output**: Alerts and Real-Time Reports

**Start:**

* **Import Libraries**: ESP8266WiFi, PubSubClient, DHT, NewPing, etc.
* **Initialize:** WiFi connection and MQTT client.
* **Setup Sensors**: Initialize temperature, humidity, gas, flame, and ultrasonic sensors.

**Loop:**

1. **Connect to WiFi:**

* If not connected, attempt to reconnect.

1. **Read Sensors**:

* Read data from temperature, humidity, gas, flame, and ultrasonic sensors.

**Function read\_sensors():**

* temperature = read\_temperature()
* humidity = read\_humidity()
* gas\_level = read\_gas()
* flame\_detected = read\_flame()
* distance = read\_ultrasonic()

1. **Process Sensor Data:**

* Analyze readings and check against thresholds.

**Function process\_data(temperature, humidity, gas\_level, flame\_detected, distance):**

* If temperature > threshold: alert\_user("Temperature too high!")
* If humidity > threshold: alert\_user("Humidity too high!")
* If gas\_level > threshold: alert\_user("Gas detected!")
* If flame\_detected: alert\_user("Flame detected!")

1. **Publish Data to MQTT:**

* Publish sensor data to MQTT broker for remote monitoring.

1. **Check Market Prices:**

* Fetch current market prices for grains from the API.

1. **Provide Alerts and Notifications:**

* Generate notifications for any detected hazards and send them via MQTT.

**End**

1. *Algorithms for Environmental Monitoring: IoT-Based Sensor Analysis*

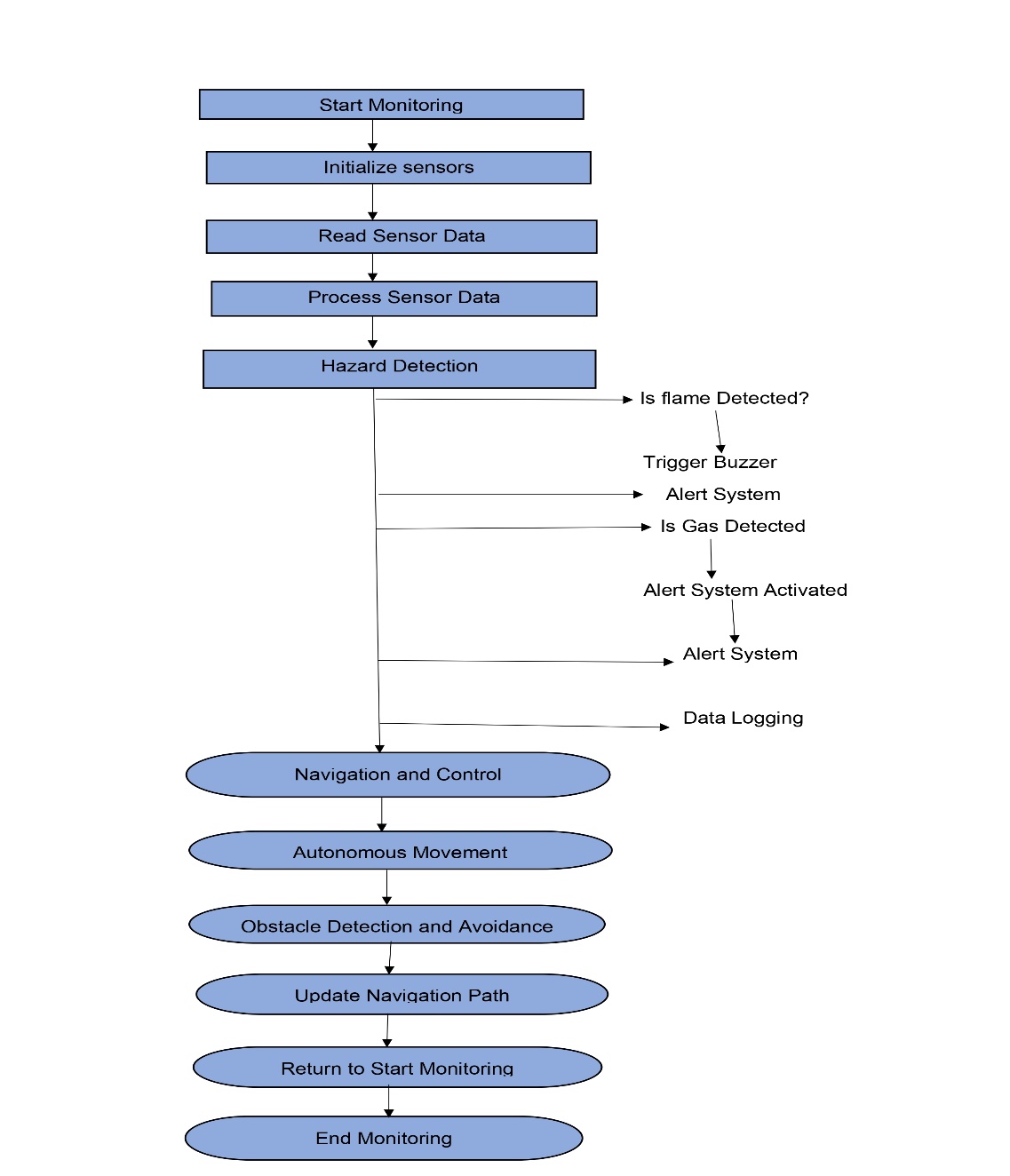
The Warewatch system employs advanced algorithms to monitor grain storage conditions using multiple IoT sensors that gather real-time data on parameters such as temperature, humidity, and gas levels. These algorithms analyze sensor readings and apply threshold-based evaluations to detect deviations from optimal conditions, sending immediate alerts to users via a mobile application when thresholds are exceeded. Additionally, machine learning techniques enhance decision-making by allowing the system to learn from historical data over time. The mobile interface provides real-time visualizations and current market prices for stored grains, empowering users with actionable insights. This integration significantly improves their ability to manage grain storage effectively and independently, ensuring minimal spoilage and optimal quality.

1. *Workflow of the Proposed Grain Monitoring System*

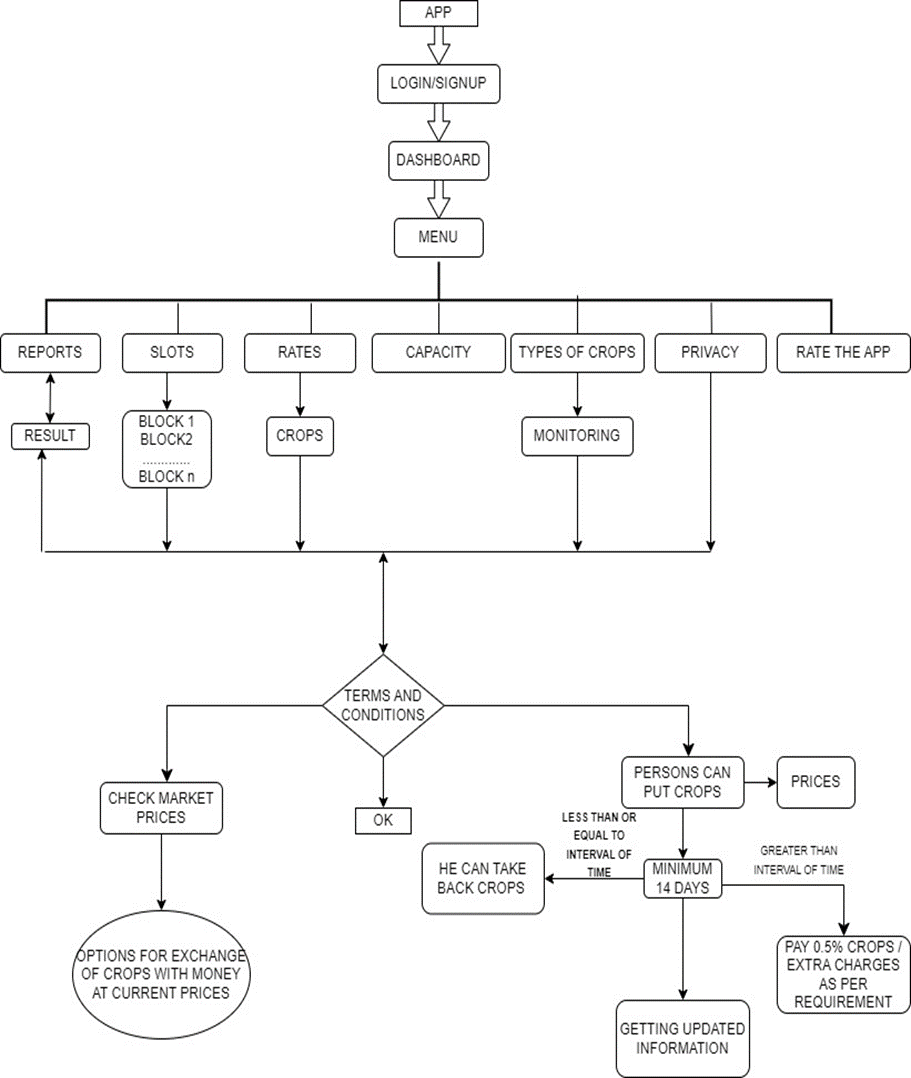
The proposed Warewatch system is designed with an intuitive interface that allows users to capture data easily. When a user presses the activation button, the system gathers information from integrated IoT sensors monitoring temperature, humidity, and gas levels. This data is processed in real-time to assess storage conditions and ensure optimal grain quality. All of this data is processed in real-time, allowing the system to assess the current storage conditions and ensure that grain quality is maintained at an optimal level.

By constantly evaluating the environmental data, the system can detect any fluctuations or anomalies that could potentially impact the quality of the stored grains. The system then sends immediate alerts to the user via a mobile application. This notification system ensures that users are informed in real-time, enabling them to take corrective actions swiftly

Additionally, the application displays real-time data and market prices for grains, empowering users to make informed decisions about their storage. This streamlined workflow enhances user engagement and promotes effective grain management, ensuring minimal spoilage and optimal quality.

 Figure 3: Block diagram of Software

Workflow of warewatch Next Gen warehouse monitoring system

IV. RESULTS AND DISCUSSION

The results of the Warewatch system for real-time environmental monitoring were highly encouraging, as shown in Table II. The system effectively identified and tracked key storage parameters, including temperature and humidity. It provided instantaneous feedback crucial for grain management. Users received real-time notifications when thresholds were exceeded. This functionality ensures timely interventions to maintain grain quality. Overall, the findings validate the system's effectiveness in minimizing post-harvest losses

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TABLE II. COMPARISON OF ENVIRONMENTAL MONITORING ALGORITHMS

|  |  |  |
| --- | --- | --- |
| ***Metrics*** | ***Warewatch Sensor Algorithm*** | ***Other Monitoring Solutions*** |
| Overall accuracy | 92.5% | NA |
| Temperature Accuracy | 94.0% | NA |
| Humidity accuracy | 91.5% | NA |
| Gas detection Accuracy | 90.3% | NA |
| Response time(ms) | 150 | 400 |
| Notificatin Speed(S) | <1 | 3 |
| Data transmission Interval(s) | 5 | 10 |

The Warewatch system is optimal for real-time environmental monitoring

* Fast Response Time: The system showcased rapid response times for alerting users to any deviations in storage conditions, essential for minimizing spoilage and ensuring grain quality.
* Accurate Monitoring: While the algorithms provided reliable data, they achieved optimal accuracy for temperature and humidity readings, ensuring that the grains were stored under ideal conditions.
* Real-Time Alerts: The immediate notifications sent to users allowed for prompt action when thresholds were exceeded, enhancing the system's practicality in real-world applications.
* Integration with Mobile App: The mobile application interface facilitated easy access to real-time data and market prices, empowering users to make informed decisions regarding their grain storage.
* Trade-off Between Speed and Accuracy: The balance between data processing speed and accuracy is well-maintained by the Warewatch system. The system processes real-time environmental data quickly, with minimal delay in sending notifications, while maintaining a high level of accuracy in monitoring key storage parameters like temperature and humidity. Compared to other grain monitoring systems, Warewatch is faster and sufficiently accurate, making it highly effective for applications requiring real-time responses to changing storage conditions.

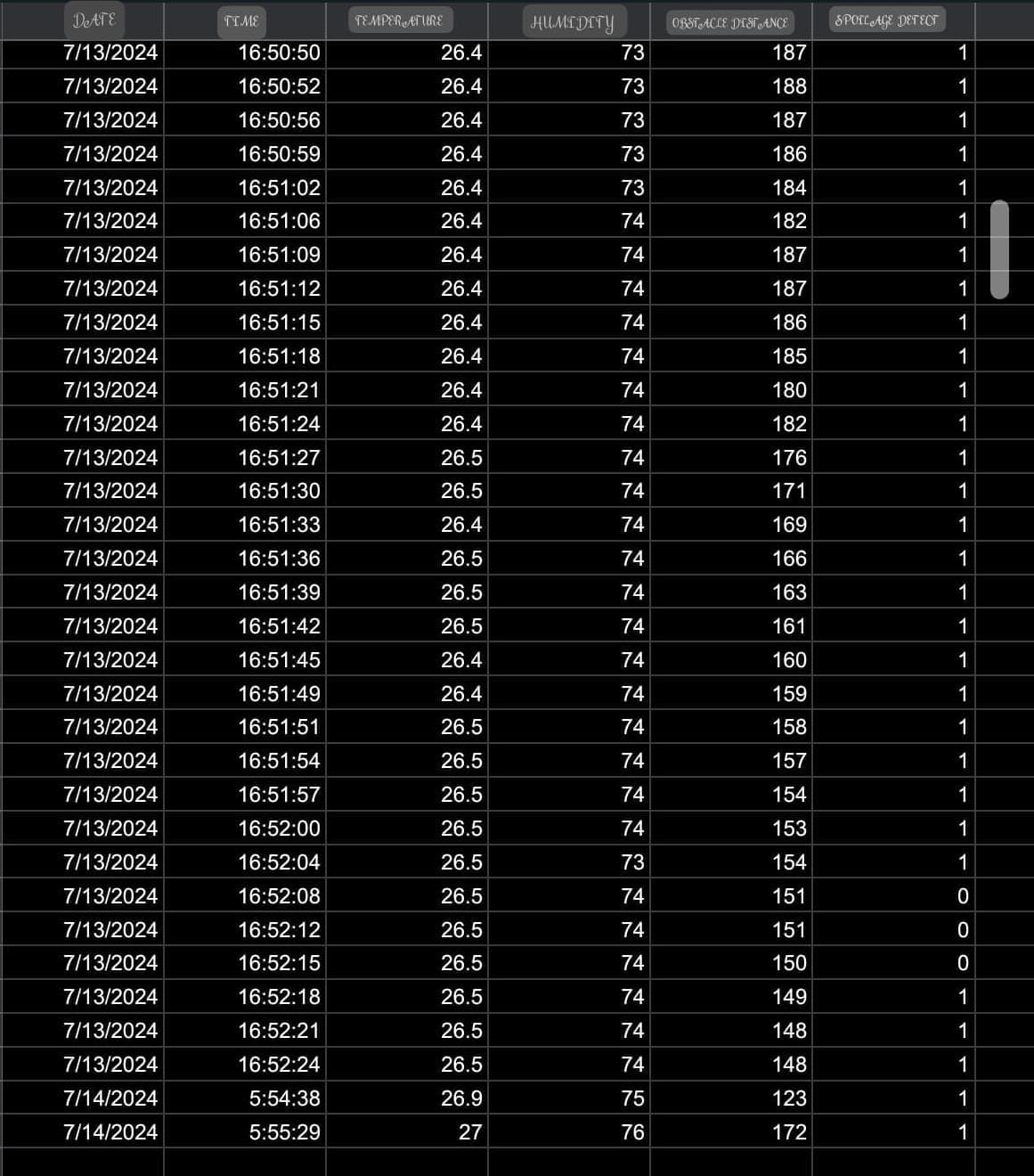


Fig 4: Performance Analysis of the warewatch

Performance Analysis: Fast and accurate monitoring of environmental parameters is made possible by the Warewatch system, which integrates multiple IoT sensors to deliver real-time data processing. This architecture is ideal for applications that require rapid response to deviations in storage conditions, enabling immediate alerts without sacrificing accuracy. As shown in Fig. 3, the system efficiently captures and processes key metrics such as temperature, humidity, and gas levels, providing a clear snapshot of the current storage environment. The system supports both single and multi-sensor monitoring, ensuring that all critical factors are accounted for.

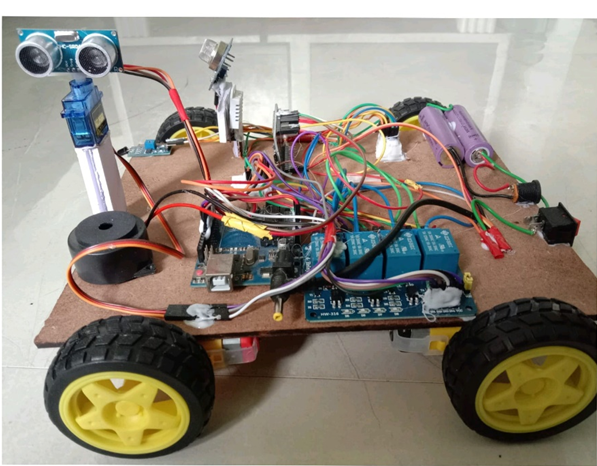


Fig 5: Warewatch Prototype Model

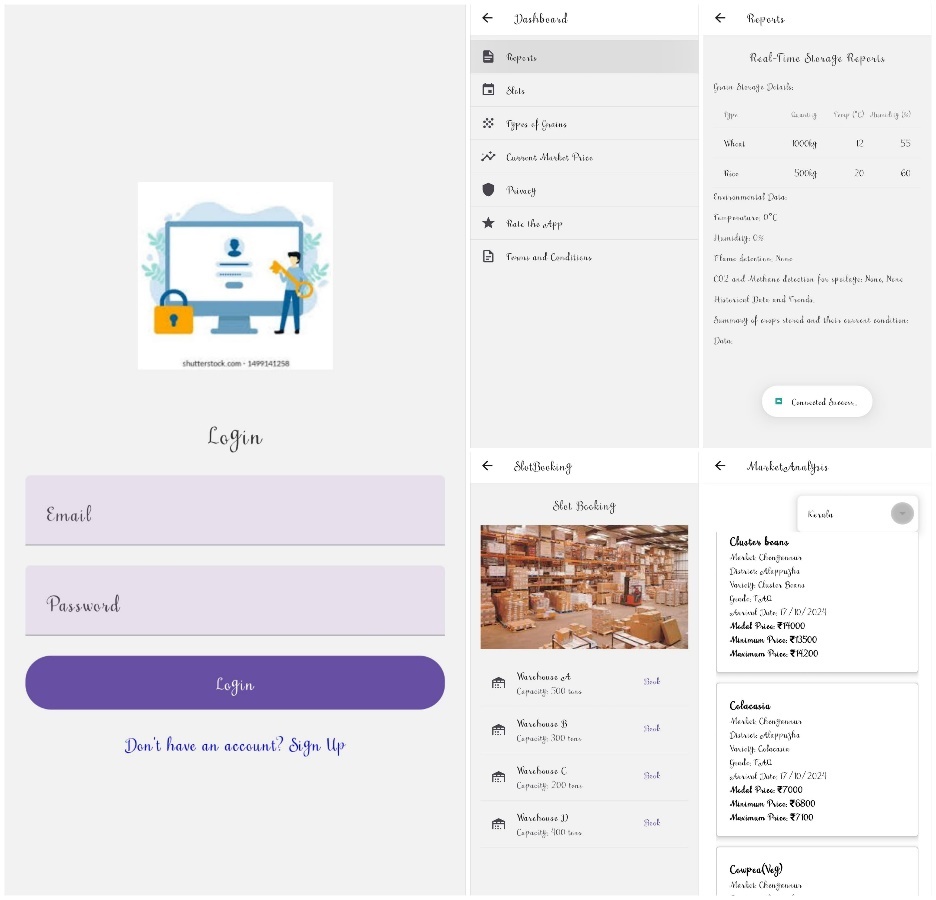


Fig 6: Warewatch Software prototype model

V. CONCLUSION

The Warewatch system provides a comprehensive solution for grain storage management, ensuring real-time monitoring and control of critical environmental conditions. Beyond the limitations of traditional storage methods, it offers advanced monitoring capabilities that help prevent spoilage and enhance the overall quality of stored grains. The integration of IoT sensors and real-time alerts empowers users to make informed decisions, significantly reducing post-harvest losses.

Looking forward, the Warewatch system can be further enhanced by incorporating advanced data analytics and predictive algorithms to improve monitoring efficiency. Future updates may include expanding the mobile application to offer more features such as market forecasting and supply chain integration. Collaboration with agricultural experts will be essential to refine the system and gather feedback from end-users. Through these efforts, the goal is to continually improve Warewatch, ensuring more effective grain storage and greater security in food management.

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