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Monitoring System for Sugar Storage using DHT22, Ultrasonic, and Light Sensors

Moh. Izzurohman[1], Sri Hasta Mulyani, I Wayan Ordiyasa

Abstract

This study develops an Internet of Things (IoT)-based monitoring system designed to maintain stable environmental conditions in palm sugar storage warehouses. The system integrates a NodeMCU ESP8266 microcontroller, a DHT22 temperature and humidity sensor, an OLED display, and a relay-controlled exhaust fan to monitor and regulate environmental parameters. Experimental evaluation was conducted using 30 measurement samples collected at 15-minute intervals in a simulated warehouse environment. The accuracy of the DHT22 sensor was assessed by comparing its readings with calibrated digital instruments. The results show that the average temperature measurement error was 0.3923°C, while the humidity error reached approximately 2.1%. The monitoring system successfully displayed real-time environmental conditions and automatically activated the exhaust fan when the temperature exceeded 30°C or humidity surpassed 67.89%. Telegram notifications were delivered with an average latency of approximately 1–2 seconds after threshold detection, demonstrating near real-time system responsiveness. Overall, the proposed IoT-based monitoring system demonstrates reliable performance in monitoring and managing environmental conditions in palm sugar storage facilities. The integration of automated control, remote notification, and web-based data visualization provides a practical and cost-effective solution for warehouse monitoring.

Keywords:
Sugar Storage, Real-time Monitoring, ESP8266, DHT22

1. Introduction

Effective storage management plays a crucial role in maintaining the quality and safety of agricultural commodities such as sugar. Sugar is highly sensitive to environmental conditions, particularly temperature and humidity, which can significantly affect its physical structure and shelf life. High humidity levels promote clumping, microbial growth, and degradation, while excessive temperature fluctuations may alter the crystallization properties of sugar. Traditional warehouse monitoring methods often rely on manual inspection and periodic measurements, which do not provide continuous environmental data and therefore limit the ability to respond quickly to unfavorable storage conditions. Researchers increasingly recognize the importance of implementing automated monitoring systems that continuously observe environmental parameters in storage facilities. For instance, recent work on wireless sensor networks (WSN) for sugar warehouse monitoring demonstrates how digital sensors and wireless communication can improve environmental awareness in storage environments. However, many systems still focus only on temperature and humidity without incorporating additional parameters that may influence storage quality, highlighting the need for more comprehensive monitoring solutions [1].

Recent developments in Internet of Things (IoT) technology have encouraged researchers to design smart monitoring systems for agricultural storage facilities. IoT-

Corresponding Author: Moh. Izzurohman, Universitas Respati Yogyakarta, izur21ade@gmail.com
Sri Hasta Mulyani, S.Kom, M.Kom, Universitas Respati Yogyakarta, hasta@respati.ac.id,
I Wayan Ordiyasa, S.Kom., M.T., Universitas Respati Yogyakarta, wayanordi@respati.ac.id

based systems enable continuous data acquisition, remote monitoring, and automated alerts when environmental conditions exceed predefined thresholds. Studies on rice storage monitoring show that integrating IoT platforms with environmental sensors allows warehouse operators to monitor temperature and humidity levels in real time, thereby reducing the risk of spoilage. Such systems typically employ microcontrollers and network connectivity to transmit data to cloud-based dashboards for visualization and analysis. Although these systems demonstrate the advantages of remote monitoring, most implementations focus primarily on staple grain commodities such as rice rather than sugar storage. Since sugar exhibits different physical properties and sensitivity to environmental changes, research specifically targeting sugar warehouse conditions remains relatively limited. Consequently, further studies are necessary to design monitoring frameworks that address the unique environmental control requirements of sugar storage facilities [2].

In addition to rice storage, several studies explore smart grain storage systems that combine environmental sensing with automated control mechanisms. These systems aim to maintain optimal storage conditions by monitoring temperature, humidity, and other environmental factors using microcontroller-based devices connected to IoT networks. Smart grain storage prototypes illustrate how real-time monitoring can improve storage efficiency and reduce the risk of product deterioration. However, these systems generally emphasize environmental control mechanisms, such as ventilation or drying processes, rather than comprehensive monitoring of additional parameters that affect storage stability. Furthermore, the majority of these implementations focus on grain silos or agricultural warehouses without considering the specific characteristics of sugar storage environments. Since sugar is prone to moisture absorption and compaction, monitoring additional variables such as material height and lighting conditions may provide better insights into storage quality. Therefore, integrating multiple sensor types into a unified monitoring system becomes essential to support more accurate environmental management in sugar warehouses [3].

Recent research on warehouse monitoring systems demonstrates the increasing importance of integrating multiple sensors to detect environmental risks in storage facilities. For example, temperature, humidity, and fire detection systems based on microcontroller platforms provide early warnings that help prevent product loss and facility damage. These systems typically use sensors connected to microcontrollers such as ESP32 to collect environmental data and transmit it to monitoring interfaces. The implementation of such systems improves safety and operational efficiency in storage environments by enabling continuous monitoring and automated notifications. Nevertheless, most studies focus primarily on risk detection, such as fire hazards, rather than the continuous monitoring of material conditions inside the warehouse. In sugar storage, maintaining stable environmental conditions is essential not only for safety but also for preserving product quality. As a result, monitoring systems must combine environmental sensing with additional measurements related to storage conditions, including material levels and ambient lighting, to ensure comprehensive warehouse management [4].

Temperature and humidity sensors play a critical role in environmental monitoring systems, particularly in IoT-based applications. The DHT22 sensor has become widely used due to its reliability, accuracy, and ability to measure both temperature and relative humidity simultaneously. Researchers frequently implement the DHT22 sensor in various monitoring applications, including solar dryer domes, pharmaceutical storage systems, and greenhouse environments. These studies demonstrate that continuous monitoring of temperature and humidity allows operators to maintain optimal environmental conditions and prevent product deterioration. In the context of storage facilities, accurate environmental sensing enables early detection of unfavorable conditions that may affect stored materials. However, most implementations focus solely on environmental monitoring without integrating additional sensors to observe other relevant parameters. In sugar storage environments, environmental monitoring should ideally work together with sensors that detect storage volume and lighting conditions to provide a more complete understanding of the warehouse environment [5][6][7].

Beyond environmental monitoring, measuring the quantity or height of stored materials is also essential for warehouse management. Ultrasonic sensors have become a popular solution for non-contact distance measurement due to their accuracy and ease of integration with microcontrollers. Numerous studies employ ultrasonic sensors such as the HC-SR04 to monitor water levels, storage tanks, and industrial containers. These systems calculate the distance between the sensor and the material surface to determine the remaining volume inside the container. The implementation of ultrasonic sensors enables automated monitoring without requiring manual inspection, thereby improving operational efficiency. In storage facilities, this technology can help monitor the height of stored materials such as grains or liquids. However, research applying ultrasonic sensing specifically to sugar storage monitoring remains relatively limited. Integrating ultrasonic sensors into a sugar warehouse monitoring system could provide valuable information about stock levels and material distribution inside storage containers [11][12][13].

In addition to environmental and material-level monitoring, lighting conditions inside storage facilities also influence operational efficiency and safety. Light sensors, such as light dependent resistors (LDR), allow monitoring systems to detect ambient light intensity and control lighting automatically. Recent IoT-based lighting systems demonstrate how LDR sensors can optimize energy consumption by activating lighting only when necessary. Such systems also provide monitoring capabilities that enable operators to observe environmental conditions remotely. In warehouse environments, lighting plays an important role in supporting operational activities and ensuring worker safety. However, excessive or insufficient lighting may affect storage conditions, particularly in facilities that require controlled environments. Integrating light sensors into an environmental monitoring system can therefore enhance the overall situational awareness within storage facilities. Despite these benefits, many storage monitoring systems do not include light sensing as part of their environmental monitoring framework [18].

The rapid advancement of IoT and cloud technologies further supports the development of integrated monitoring systems that combine multiple sensors and real-time data communication. Modern IoT architectures enable environmental data to be transmitted to cloud platforms where it can be analyzed, visualized, and accessed remotely by warehouse operators. Cloud-enabled monitoring systems provide advantages such as real-time alerts, historical data analysis, and remote device control. Researchers demonstrate that integrating microcontroller-based sensor nodes with cloud services significantly improves the efficiency and scalability of environmental monitoring applications. These technologies open opportunities to design comprehensive monitoring systems that combine temperature, humidity, material height, and lighting sensors in a single integrated platform. Therefore, developing a multi-sensor monitoring system for sugar storage that utilizes IoT connectivity represents a promising approach to improve storage management, maintain product quality, and enhance operational efficiency in warehouse environments [19][20].

2. Related Works

Previous studies investigated environmental monitoring systems in sugar storage facilities using wireless sensor technologies. Mahendra et al. developed a wireless sensor network (WSN) system that monitored digital scales and environmental conditions in a sugar warehouse using LoRa communication. Their system successfully transmitted temperature and humidity data over long distances and enabled remote observation of warehouse conditions. The implementation demonstrated that wireless communication significantly improved monitoring coverage in large storage areas. However, the system mainly focused on environmental monitoring and weight measurement without integrating additional sensors that could measure material height or other storage parameters. As a result, the monitoring capability remained limited in terms of observing the overall storage condition of sugar inside the warehouse [1].

Several researchers also explored IoT-based environmental monitoring systems for agricultural storage. Alfira et al. designed an IoT-based temperature and humidity control system for rice storage facilities. Their study used environmental sensors connected to a microcontroller to monitor storage conditions and activate actuators when the environment exceeded safe thresholds. The system successfully maintained stable conditions for rice storage and demonstrated the potential of IoT technology for smart warehouse management. Despite these advantages, the research primarily focused on control mechanisms rather than comprehensive monitoring. The system also did not include sensors that could detect storage levels or material distribution, which limited its applicability for warehouses that require integrated monitoring of both environmental and inventory conditions [2].

Pratama et al. proposed a smart grain storage prototype based on Internet of Things technology. Their system monitored temperature and humidity conditions and transmitted the collected data to an online monitoring platform. The study showed that real-time monitoring improved the ability of warehouse managers to detect unfavorable environmental conditions and take corrective actions. The system also highlighted the importance of continuous data collection for maintaining the quality of stored agricultural commodities. However, the design focused primarily on environmental sensing and did not consider additional parameters such as storage volume or lighting conditions. Consequently, the monitoring system did not provide a complete overview of the physical storage environment [3].

Other studies investigated monitoring systems designed specifically for warehouse safety and environmental detection. Anggraini et al. developed a monitoring prototype that detected temperature, humidity, and fire hazards in rice warehouses using an ESP32 microcontroller. Their system improved warehouse safety by providing early warnings when environmental parameters exceeded normal limits. The integration of multiple sensors demonstrated the effectiveness of microcontroller-based monitoring platforms for storage facilities. Nevertheless, the system emphasized hazard detection rather than routine monitoring of storage quality. The system also lacked mechanisms to monitor the quantity or height of stored materials, which limited its capability for inventory monitoring and warehouse management [4].

Environmental monitoring applications widely used temperature and humidity sensors to ensure stable storage conditions. Ma’arij and Yudhana implemented a temperature and humidity monitoring system in a solar dryer dome using IoT technology. Their study demonstrated that sensors such as DHT22 could accurately measure environmental parameters and support automated monitoring processes. Similarly, Maulana and Haryanti designed a pharmaceutical refrigerator monitoring system that used DHT22 sensors to maintain proper temperature and humidity levels for medical storage. These studies confirmed that environmental sensors played an essential role in maintaining product quality in controlled environments. However, most of these systems focused exclusively on environmental monitoring and did not integrate additional sensing capabilities for monitoring material levels or other operational factors [5][6].

Researchers also investigated the use of ultrasonic sensors for non-contact measurement in monitoring systems. Aini et al. developed a water tank level monitoring system using an HC-SR04 ultrasonic sensor and Arduino Uno. Their system measured the distance between the sensor and the water surface to determine the remaining volume inside the tank. Similarly, Samosir and Hidayat designed a water volume monitoring system that successfully calculated water levels using ultrasonic distance measurements. These studies demonstrated that ultrasonic sensors provided reliable and cost-effective solutions for monitoring material height in storage containers. However, most implementations focused on liquid monitoring applications, and limited research explored the use of ultrasonic sensors for monitoring solid materials such as agricultural commodities or sugar storage [11][12].

Other research examined the integration of ultrasonic sensors in industrial and IoT monitoring systems. Yusuf et al. developed an IoT-based monitoring system for fuel storage tanks using ultrasonic sensors. Their system enabled continuous monitoring of fuel levels and transmitted real-time data to remote monitoring platforms. The study highlighted the advantages of ultrasonic sensors for inventory monitoring and automation in industrial environments. In addition, Apsari et al. applied linear regression techniques to improve the accuracy of ultrasonic-based water level monitoring. Although these studies demonstrated the effectiveness of ultrasonic sensors in monitoring applications, they primarily addressed liquid storage environments rather than solid material storage systems such as grain or sugar warehouses [13][17].

Recent research also explored the use of IoT and cloud platforms for real-time environmental monitoring. Pambudi et al. implemented an IoT-based automatic lighting and monitoring system using LDR sensors to detect ambient light conditions. Their system optimized lighting control and improved energy efficiency in indoor environments. Furthermore, Hasib and Akib developed a cloud-enabled IoT system that allowed real-time environmental monitoring and remote device control using cloud services. These studies demonstrated that integrating sensors with cloud platforms significantly enhanced monitoring accessibility and system scalability. Nevertheless, most implementations focused on general environmental monitoring or smart building applications and did not specifically address integrated monitoring systems designed for agricultural storage environments such as sugar warehouses [18][19].

3. Proposed Method

This study builds an Internet of Things (IoT)-based monitoring system to maintain stable environmental conditions in palm sugar storage warehouses. We construct a monitoring framework that observes temperature and humidity in real time and automatically responds when environmental parameters exceed predefined thresholds. The system also sends notifications through a Telegram messaging service to inform warehouse operators about abnormal conditions. In addition, the system activates an exhaust ventilation mechanism to reduce excessive heat and humidity inside the storage area. Through this approach, the monitoring system supports continuous supervision and helps minimize quality degradation of stored palm sugar caused by unstable environmental conditions.

To implement the proposed monitoring system, we construct a hardware architecture that integrates sensing, processing, and control components. This study builds the core system using a NodeMCU ESP8266 microcontroller due to its built-in Wi-Fi capability and flexible GPIO interface, which allows efficient data processing and communication with external devices. We utilize a DHT22 sensor to measure temperature and relative humidity because it provides higher measurement accuracy compared with other low-cost sensors. The system activates a 12V exhaust fan through a two-channel relay module when the detected temperature exceeds 30°C or the humidity surpasses 67.89%. An I2C OLED 128×64 display shows real-time environmental information directly at the monitoring location. We supply power using a 12V 2A DC adapter connected to a step-down converter to match the voltage requirements of the electronic components. To ensure structural stability and protection, we assemble the prototype inside an acrylic PET casing supported by nylon spacers, bolts, and a breadboard for circuit prototyping.

In addition to the hardware configuration, we construct a software architecture that enables data acquisition, control logic, and remote monitoring. This study builds the firmware using the Arduino IDE, which allows the NodeMCU to read sensor values, process environmental thresholds, and control the relay module. We integrate the Telegram Bot API to provide real-time notifications and remote interaction with the monitoring system. Through this interface, users receive alerts and can send commands such as activating the ventilation system or requesting the current environmental status. We also develop a backend system using PHP to process incoming data from the ESP8266 through HTTP communication. The collected data are stored in a MySQL database to maintain historical records of temperature, humidity, and measurement time. Furthermore, we design a web interface using HTML, CSS, and JavaScript to visualize environmental data trends and allow remote access through a standard web browser. The XAMPP platform provides the local server environment for hosting the database and web dashboard during development and testing.

To ensure systematic development, this study builds the monitoring system using a structured engineering design process. We begin with problem identification by analyzing the challenges associated with maintaining stable environmental conditions in palm sugar storage warehouses. After defining the problem, we conduct a literature review to evaluate existing monitoring technologies, including IoT systems based on ESP8266 microcontrollers, DHT22 environmental sensors, and remote notification platforms. We then construct a system design using block diagrams and flowcharts to describe the interaction between the sensors, microcontroller, relay module, display, web server, and Telegram communication platform. The final stage involves prototype development, where we assemble the hardware components and implement the firmware and web-based monitoring interface. Fig. 1 depicts the System Block Diagram that capable of autonomously monitoring environmental conditions.

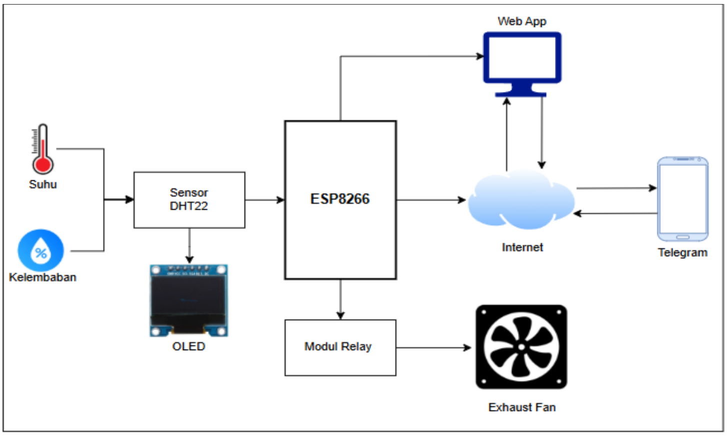

Fig. 1 System Block Diagram

Fig.1 depicts the prototype monitoring system and conducts a series of functional tests to evaluate the reliability of the hardware components. We construct the testing scenario in a simulated warehouse environment to observe the behavior of the sensors, display, and actuator under controlled conditions. The testing procedure includes sensor calibration, verification of relay response, evaluation of Telegram notification accuracy, and validation of real-time data display on the OLED screen. During the experiment, we manually manipulate environmental conditions to exceed the predefined thresholds in order to observe whether the system automatically activates the exhaust fan and sends alerts to users. This testing process ensures that each component operates correctly and that the integrated system performs according to the design specifications.

To ensure proper communication between devices, this study builds a hardware configuration that connects the sensors and actuators to the ESP8266 microcontroller. The

DHT22 sensor measures temperature and humidity and transmits the data to the microcontroller through a digital pin. Meanwhile, the OLED display presents real-time monitoring results directly at the observation point, and the relay module controls the exhaust fan based on system logic. The connection configuration between components and the ESP8266 microcontroller is presented in Table 1.

Table 1. Hardware Connection Configuration

Component	**Pin**	**ESP8266 Connection**
DHT22 Sensor	(+)	3V
	OUT	D5
	(-)	GND
OLED Display	GND	GND
	VCC	3.3V
	SCL	D1
	SDA	D2
Relay Module	(+)	3V
	IN	D6
	(-)	GND

After completing system integration, this study evaluates the performance of the prototype through accuracy testing and functional analysis. We compare the temperature and humidity readings from the DHT22 sensor with measurements obtained from a calibrated digital thermometer to assess sensor accuracy and response time. In addition, we analyze the reliability of data transmission, the stability of data logging in the database, and the responsiveness of Telegram notifications. Feedback from test users is also collected to evaluate the usability of the monitoring interface and remote control features. Through this structured testing and evaluation process, the developed system demonstrates reliable monitoring performance and provides a practical solution for maintaining environmental stability in palm sugar storage warehouses.

4. Experimental Setup

To evaluate the performance and reliability of the proposed IoT-based monitoring system, this study conducted several experiments in a simulated palm sugar storage environment. The objective of the testing phase was to verify sensor accuracy, system responsiveness, data transmission stability, and the effectiveness of the automated control mechanism. All hardware components were assembled into a functional prototype enclosed in an acrylic casing. The DHT22 sensor was connected to the NodeMCU ESP8266 through GPIO D5 to collect temperature and humidity data. An I2C OLED display was integrated via GPIO D1 (SCL) and D2 (SDA) to present real-time environmental readings. Meanwhile, a relay module connected to GPIO D6 controlled a 12V exhaust fan that acted as the ventilation actuator when environmental thresholds were exceeded. The system received power from a 12V DC adapter combined with a step-down converter to provide stable voltage to the ESP8266 and other components. The wiring configuration of the system components is summarized in Table 2.

Table 2. Wiring Diagram

Components	**ESP8266 Pin**
DHT22 Sensor (OUT)	D5 (GPIO14)
OLED SCL	D1
OLED SDA	D2
Relay IN	D6

After assembling the hardware, the firmware was deployed to the NodeMCU using the Arduino IDE, incorporating libraries for DHT sensor reading, OLED display control, HTTP communication, and Telegram Bot API integration. The system defined environmental thresholds at 30°C for temperature and 67.89% for humidity. When these limits were exceeded, the relay activated the exhaust fan and the system automatically sent a notification through Telegram. A PHP-based server running on XAMPP received sensor data via HTTP GET requests from the ESP8266 and stored the information in a MySQL database. A web dashboard developed using standard web technologies allowed users to visualize historical environmental data and monitor system status remotely. The testing environment was simulated indoors using a controlled heat source and humidifier to gradually increase temperature and humidity levels. Sensor readings were compared with calibrated digital thermometer and hygrometer measurements. Each experiment was conducted at 15-minute intervals across 30 observation samples. Additional tests involved sending Telegram commands such as **/on**, **/off**, **/status**, and **/auto** to verify manual and automatic fan control features. System performance was evaluated based on sensor accuracy, notification latency, data transmission stability, and the response time of the exhaust fan after environmental thresholds were detected.

5. Result and Analysis

This section presents the experimental results obtained from the implementation of the IoT-based temperature and humidity monitoring system for palm sugar storage, followed by an analysis of system performance and reliability. Sensor accuracy testing was conducted using 30 measurement samples collected at 15-minute intervals. The readings obtained from the DHT22 sensor were compared with a calibrated digital thermometer and hygrometer to determine measurement accuracy. The results show that the average temperature error reached 0.3923°C, while the relative humidity error was approximately 0.021 or 2.1%. These findings indicate that the DHT22 sensor provides sufficiently accurate measurements for environmental monitoring applications in warehouse environments. The acceptable error range supports the use of DHT22 as a cost-effective sensing component for IoT-based monitoring systems designed for agricultural storage facilities.

Table 3. Sensor Accuracy Test Results

Parameter	Reference Instrument	DHT22 Average Reading	Average Error	Error Percentage
Temperature	Digital Thermometer	Measured Value	0.3923 °C	–
Humidity	Digital Hygrometer	Measured Value	0.021	2.1 %

In addition to sensor validation, the system successfully demonstrated real-time monitoring and automated alert functionality. The OLED display continuously presented live temperature and humidity readings, allowing on-site observation of environmental conditions. When the temperature exceeded 30°C or the humidity surpassed 67.89%, the system automatically activated the exhaust fan through the relay module and sent notification messages to users via Telegram. The observed notification delay ranged between 1–2 seconds after the threshold was detected, indicating near real-time system response.

The system also demonstrated stable data transmission and logging performance. Sensor readings were transmitted via Wi-Fi using HTTP communication to a local server, where the data were stored in a MySQL database and visualized through a web interface. The dashboard displayed both real-time values and historical trends complete with timestamp information, allowing users to analyze environmental patterns in the warehouse.

During the experimental period, no data transmission failures or packet losses were observed, indicating stable communication between the ESP8266 and the server. Overall, the monitoring system operated reliably under the testing conditions and effectively supported warehouse environment supervision. Nevertheless, several limitations remain, including the moderate precision level of the DHT22 sensor, the need for additional nodes when deployed in larger warehouses, and the dependency on stable Wi-Fi connectivity for remote notification delivery. User evaluation results further indicated positive feedback, with more than 85% of respondents reporting that the system was easy to operate and useful for monitoring warehouse conditions.

6. Conclusion

This study developed and implemented an Internet of Things (IoT)-based monitoring system designed to maintain stable environmental conditions in palm sugar storage warehouses. The system integrated a NodeMCU ESP8266 microcontroller, a DHT22 temperature and humidity sensor, an OLED display, and a relay-controlled exhaust fan. Experimental results demonstrated that the system successfully monitored environmental conditions in real time and automatically responded when predefined thresholds were exceeded. The DHT22 sensor showed acceptable measurement performance with an average temperature error of 0.3923°C and a relative humidity error of approximately 2.1%. These results indicate that the sensor provides sufficient accuracy for warehouse monitoring applications, particularly in low-cost IoT-based environmental control systems.

The implementation of the real-time monitoring and notification mechanism also performed effectively during the testing phase. The system continuously displayed environmental data on the OLED screen and automatically activated the exhaust fan when temperature exceeded 30°C or humidity exceeded 67.89%. At the same time, Telegram notifications were successfully delivered to users with an average latency of approximately 1–2 seconds after threshold detection. Data transmission from the ESP8266 to the web server remained stable, and all sensor readings were successfully stored in the MySQL database without data loss, enabling real-time visualization and historical data analysis through a web-based dashboard.

Overall, the proposed IoT-based monitoring system demonstrated reliable performance in maintaining environmental awareness within a palm sugar storage environment. The integration of sensor monitoring, automated ventilation control, real-time notifications, and data logging provides an effective and practical solution for warehouse environmental management. Although the system showed promising results, further improvements may include the deployment of multiple sensor nodes for larger warehouse coverage, the use of higher-precision sensors for critical environments, and the integration of alternative communication methods to reduce dependence on Wi-Fi networks. Despite these limitations, the developed prototype offers a scalable and cost-efficient approach to supporting the preservation of palm sugar quality during storage.

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