Web Enabled IOT based Warehouse Management System for Agricultural Products

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ABSTRACT
Maintaining the quality of stored products in a warehouse requires an optimal environment that controls temperature and humidity levels. This article proposes a warehouse management system, utilizing a DHT11 sensor and Adafruit library, to monitor and control temperature and humidity levels in real-time. The system also incorporates an allocation algorithm that assigns compartments to users based on their product requirements. The system was implemented and tested in a warehouse setting, demonstrating a substantial enhancement in product quality and a reduction in waste. The results indicate the system's effectiveness in maintaining a controlled environment and providing users with essential information to make informed decisions. Furthermore, the proposed system has the potential to help warehouse managers optimize their operations, reduce waste, and improve the overall quality of stored products.

General Terms
The proposed system offers warehouse managers the opportunity to optimize operations, minimize waste, and enhance product quality.

Keywords
quality control, monitoring and regulating, cost-effective solution, real-time temperature control, optimal temperature, humidity levels.

1. INTRODUCTION
The management of perishable goods is a critical aspect of the supply chain, as the quality of these items can deteriorate rapidly over time. To address this challenge, maintaining optimal temperature and humidity conditions in the warehouse becomes crucial. In recent years, businesses have increasingly turned to Warehouse Management Systems (WMS) to automate the monitoring and control of environmental conditions in warehouses. This approach offers advantages over traditional manual methods, such as reducing costs, saving time, and minimizing human errors [10][12].

A WMS integrates sensors, microcontrollers, and software to provide real-time monitoring and control of temperature and humidity conditions. By adopting a WMS, businesses can effectively reduce waste, boost productivity, and enhance overall profitability. Our proposed WMS solution utilizes the DHT11 sensor, Adafruit library, and compartment allocation based on specific user requirements. This innovative system is designed to deliver accurate and reliable monitoring and control of temperature and humidity conditions in warehouses.

The WMS incorporates a mobile application feature that allows users to efficiently allocate compartments according to their specific needs. This capability enhances goods management, resulting in improved productivity and waste reduction. The flexibility and adaptability of the WMS to accommodate the unique requirements of warehouses and employees play a vital role in ensuring effective and efficient operations. Leveraging this advanced technology empowers warehouses to optimize space utilization, streamline goods management processes, and realize significant cost savings while enhancing customer satisfaction.

The implementation of our proposed WMS involves a thorough analysis of warehouse requirements, system design, and development, rigorous testing to ensure accuracy and reliability, and deployment in the warehouse environment. During the implementation phase, meticulous attention is given to tailoring the WMS to meet the specific needs of the warehouse and its employees. Rigorous testing is conducted under diverse conditions to evaluate the system's performance and ensure its accuracy and reliability. Once deployed, continuous monitoring and maintenance are carried out to ensure optimal system performance.

In conclusion, effective management of perishable goods is essential for maximizing profitability in the supply chain. Implementing a WMS offers a reliable and automated solution for monitoring and controlling temperature and humidity conditions in warehouses. Our proposed WMS, featuring the DHT11 sensor, Adafruit library, and compartment allocation, delivers accurate and dependable monitoring and control capabilities. By embracing this WMS solution, businesses can boost productivity, minimize waste, and enhance overall profitability.

2. LITERATURE SURVEY
In the context of temperature and humidity control, several studies have proposed the use of WMS to automate the monitoring and control of environmental conditions in a warehouse.

In this research paper [1] authors explores the potential of IoT technology in agriculture to create a ”smart agriculture” system that enables farmers to monitor and control various aspects of their farm operations in real-time. The paper discusses various IoT-based smart agriculture applications, the benefits of using IoT technology in agriculture, and the challenges of implementing IoT-based smart agriculture systems. The authors suggest that collaboration between governments, policymakers, and industry players is crucial to promote the adoption of IoT technology in agriculture.

Authors of research paper [2] has explores how IoT and smart warehouse technology can improve the efficiency, accuracy, and safety of warehouse operations. The paper discusses the benefits of using IoT technology in warehouses, such as reduced costs and improved inventory management, as well as the challenges of implementing IoT-based smart warehouses. The authors propose a framework for developing IoT-based smart warehouses, which includes integrating various technologies and robust data analytics. The paper suggests that embracing IoT technology is necessary for companies to stay competitive in the logistics industry.

Tejas et al. proposed a Warehouse Inventory Management System in their paper [3] that utilizes IoT and an open-source framework. The system is highly significant in the industry due to the profits it can generate. Numerous studies have supported RFID technology as an efficient identification system that has brought a positive impact on the warehouse industry by enhancing efficiency, making product tracking easier, and eliminating the risk of theft through the use of Electronic Product Codes. The IoT allows sensors to be connected for independent services and applications. In the perception layer, data from the physical world are gathered using WSN, sensors, and RFID systems. In the network layer, it enables transparent data transmission, while the service layer includes a data management sub-layer and an application sub-layer. The use of RFID and IoT is highly beneficial for localization, tracking, and positioning applications. The Warehouse Inventory Management System allows users to track the flow of products easily.

In the paper [4], researchers came up with the idea of a Warehouse Management System for smart logistics that utilizes the Internet of Things (IoT). The study aims to evaluate the effectiveness of the system for low-volume, high-product mix situations. The researchers suggest using an advanced WMS integrated with fuzzy clustering to replace manual operation, enhance the efficiency of the order-picking process, and suggest the most suitable order-picking method. This will also reduce the workload of the picker and eliminate unnecessary processes. The research is in line with Industry 4.0, the fourth industrial revolution, which involves the digitization and automation of the manufacturing environment and the creation of a digital value chain.

Authors proposed a Smart Inventory Management System in their paper [5], which utilizes low-energy devices based on the Internet of Things (IoT). The authors conducted a statistical case study on two groups within the same organization. They discovered that using an RFID tag, which can carry specific information about an object and be attached to any physical surface, was more efficient and accurate than traditional barcode scanners. Although passive tags are cheaper, they require power from the reader to transmit data. The proposed system automates asset tracking and reporting, which saves up to 50 working hours per month and reduces the probability of human error.

The study conducted in paper [6] by the researchers proposes a project called "Smart Warehouse Monitoring Using IoT." The aim of the project is to use sensors to capture information related to temperature, moisture, earthquakes, and fires and send alerts using IoT technology. The Central Warehousing Corporation (CWC) stores and handles more than 400 types of merchandise, including agricultural products, industrial raw materials, finished goods, and perishable and hygroscopic items. To prevent storage loss of perishable goods and food grains, the CWC employs various methods such as quality checks, regular inspections, proper documentation, age analysis, sanitation, physical condition assessments of storehouses, and administration.

In their paper [7] titled "Study on IoT-based Architecture of Logistics Service Supply Chain", authors investigated the influence of IoT on the logistics service supply chain (LSSC), examining various aspects such as connotation, conceptual modal, risk management, profit distribution, order allocation, coordination, quality coordination, cooperation and coordination, and management control system. They analyzed the impact of IoT on logistics/service flow, information flow, and fund flow in the LSSC, and put forward an IoT-based architecture for the LSSC.

In the paper [8] authors have proposed an Internet-of-Things (IoT)-based architecture for real-time warehouse management that divides the warehouse into multiple domains. The proposed architecture uses different viewpoints and a generic IoT-based prototype system to ensure efficient data collection and transmission. The authors deployed the proposed IoT based solution in the warehouse of a textile factory for validation testing, and the results showed the effectiveness of the proposed architecture.

The authors in their paper [9] proposed a framework to monitor the warehouse conditions that affect grains, such as temperature, humidity, CO, motion, vibration, and smoke. The system uses an ESP32 WiFi module to gather data from sensors and transmits the information to the Node-red dashboard via an MQTT broker. Multiple IoT nodes are installed at different locations within the warehouse, which enables the farmer to receive information about the warehouse environment through SMS and email notifications.

In the paper [10] authors proposed that the model takes into account static and dynamic factors of the storage process and applies to a warehouse storing food products, considering organizational, legal, and technical aspects, and hazards that can affect all aspects. The designed model's originality lies in its comprehensive consideration of all aspects and hazards that can affect the system.

In their study [11], the authors, found that the warehouses in the East Shewa Zone were of substandard quality, which led to deterioration in the quality of goods and disputes over compensation. The authors also noted that the warehouses were heavily reliant on manual labor and lacked appropriate equipment. To address these issues, the authors recommended the adoption of the first-in, first-out (FIFO) principle, regulations on truck movements, and the use of weighbridges to expedite the offloading process. Furthermore, the authors suggested implementing traceability measures using technologies like RFID to enhance inventory management.

The authors of [12] proposed the features and functions of the "Smart Automation for Agriculture" device, which was developed to solve problems faced by farmers. The device uses sensors, modules, and an Arduino kit to monitor soil pH and moisture, temperature, and humidity, and provide smart irrigation and warehouse management. It can be controlled remotely through a smart device or computer connected to the internet. The study emphasizes the importance of using engineering techniques to benefit society and support agriculture.

In their paper [13], authors proposed IoT-based supply chains use an information-sharing mechanism to send product information to the management database and receive feedback, allowing manufacturers, distributors, and retailers to respond to market supply and demand information on time and balance supply and demand and prevent product price fluctuations. Companies can help resolve product security issues by controlling the supply chain.

Kim et al., in their paper [14] titled “Smart Integrated Multiple Tracking System Development for IoT-based Target-oriented Logistics Location and Resource Service” investigates different technologies such as GPS, RFID, sensors, LAN, Wireless-Network, and Wi-Fi that can be used for tracking systems. The study also emphasizes the importance of location-based services (LBS) and their integration into these tracking systems to prevent the loss of children or goods. The proposed system aims to enhance the measurement technology of LBS in various applications.

In summary, the literature survey indicates that WMS, sensor technology, and compartment allocation algorithms have been widely investigated in various aspects of warehouse management. However, there is still a need for further research in developing WMS that incorporate the DHT11 sensor, Adafruit library, and compartment allocation to improve the efficiency and accuracy of temperature and humidity control in a warehouse environment.

3. SYSTEM METHODOLOGY

This section provides an overview of the purpose behind the development of the system, the research methodology utilized, and the hardware and software architecture employed. Additionally, it discusses the various modules, components, interfaces, and data requirements necessary to achieve the predetermined objectives.

3.1 System Overview

The integration of IoT technology in agriculture warehouses aims to enhance control for farmers by bridging the gap between the physical and digital realms. The IoT system comprises five layers: perception, transport, processing, application, and business layers. This work primarily focuses on the first three layers of IoT, namely perception, transport, and processing.

The perception layer encompasses the implementation of sensors responsible for data collection, while the transport layer handles wireless data transfer. The processing layer is responsible for visualizing the collected data [1][9].

The system architecture involves the utilization of a DHT11 sensor connected to an Arduino Uno board, which, in turn, is connected to a computer via USB. The system software is developed using the Arduino Integrated Development Environment (IDE) and the Adafruit library. The software incorporates code to read temperature and humidity data from the sensor and control the warehouse's temperature and humidity levels using a heater and a humidifier.

Furthermore, the system incorporates a web application that enables users to allocate compartments based on their specific requirements. This web application is developed using React.js and hosted on a web server. To ensure secure access, the web application includes a login system that allows only authorized users to allocate compartments.

Within the warehouse, IoT nodes are strategically deployed at different locations. These nodes, designed using ESP8266 and various sensors, provide real-time information to farmers via text messages on their mobile phones. The underlying concept of our work is to establish an efficiently organized warehouse by harnessing the capabilities of IoT.

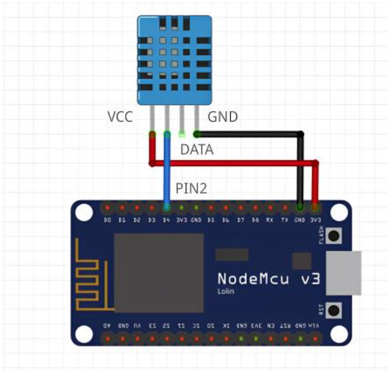

Fig 1: DHT11 Sensor Interfaced with ESP8266 and Arduino Uno board

3.2 System Implementations

3.2.1 Requirements Analysis

Before the development of a Warehouse Management System (WMS). The analysis Fig. 1. DHT11 Sensor Interfaced with ESP8266 and Arduino Uno board process includes several critical factors, such as identifying the warehouse size, types of goods stored, ideal temperature and humidity conditions for the goods, and user requirements for compartment allocation. The ideal temperature and humidity levels for different goods can vary, and the WMS must be designed accordingly to prevent damage or spoilage.

Moreover, conducting a detailed analysis is crucial to determine the number of sensors required, their optimal placement, and the overall system design. The strategic placement of sensors plays a pivotal role in accurately capturing the necessary data. The number of sensors needed can vary depending on the size of the warehouse. Additionally, the WMS must be able to cater to the specific needs of the goods stored. For example, a warehouse that stores perishable goods may require a WMS that is specifically designed to maintain precise temperature and humidity levels to prevent damage or spoilage.

3.2.2 Sensor Selection

When considering sensor options for temperature and humidity monitoring in a Warehouse Management System (WMS), several factors come into play. The selection of the DhTT11 sensor was primarily driven by its high accuracy, which is crucial for ensuring reliable and trustworthy temperature and humidity readings. This accuracy helps to prevent false alarms and reduces the risk of costly errors in warehouse operations.

Furthermore, the relatively low cost of the DhTT11 sensor played a significant role in our decision-making process. This cost-effectiveness makes it an optimal solution for the WMS, particularly when considering the size and scale of the warehouse. The sensor's affordability simplifies the development process and facilitates the seamless transmission of sensor data to the cloud for processing and analysis.

The ease of integration offered by the DhTT11 sensor also played a vital role in our decision. Its seamless integration saves valuable time and effort, which is essential for meeting project timelines and deadlines. These factors are of utmost importance in ensuring reliable and efficient temperature and humidity monitoring within the warehouse environment.

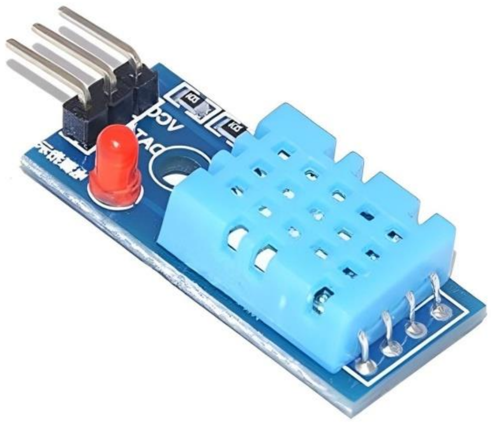

Fig 2: DHT11 Humidity Sensor

3.2.3 Microcontroller

When developing a system that involves monitoring data from sensors, the choice of microcontroller plays a vital role. In this case, the ESP8266 microcontroller was selected based on its cost-effectiveness, low power consumption, and Wi-Fi connectivity [18][2]. This microcontroller serves the purpose of reading data from the DHT11 sensor and transmitting it to the cloud platform for analysis and real-time display to the user.

To streamline the development process, the integration of the Adafruit library was incorporated. This library facilitates faster and more efficient development of the system. By utilizing this combination of hardware and software, the Warehouse Management System (WMS) can effectively read and transmit sensor data in a cost-effective manner [5][3].

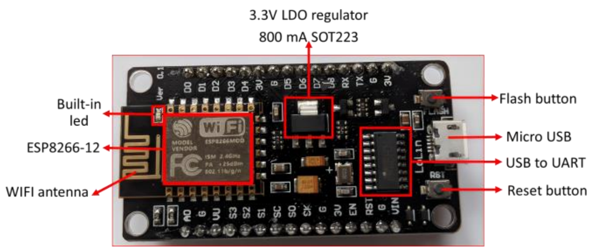

Fig 3: ESP8266 Architecture and Arduino GUI

3.2.4 Cloud Computing

The utilization of a cloud platform provides numerous advantages, such as scalability and security [15]. In the case of the Warehouse Management System (WMS), the decision was made to adopt the Adafruit IO platform as the chosen cloud service. This platform enables users to monitor and control the real-time temperature and humidity conditions of the warehouse. It also offers a user-friendly interface for data visualization and analysis.

By leveraging cloud computing, the WMS benefits from efficient storage and processing capabilities, allowing for the handling of large volumes of data in a cost-effective manner. Furthermore, the scalability of the platform ensures that the system can accommodate future growth and expansion, ensuring its adaptability over time.

3.2.5 Cloud Integration

To establish a seamless connection between the microcontroller and the cloud platform, Wi-Fi technology is employed as the communication medium. The Adafruit IO API is utilized to facilitate the exchange of data between the microcontroller and the cloud platform. This API enables real-time streaming of data and grants control over the temperature and humidity conditions of the warehouse. Additionally, it allows for the retrieval of historical data, enabling further analysis and decision-making processes.

The utilization of Wi-Fi technology offers a reliable and rapid mode of communication, ensuring that the data is transmitted promptly and efficiently. Furthermore, the Adafruit IO API is designed to be user-friendly and straightforward, simplifying the integration process for developers working on their projects.

3.2.6 Application

An application is developed to facilitate users in allocating compartments according to their specific requirements. This user-friendly application is thoughtfully designed with a simple and intuitive interface, enabling users to allocate compartments based on various factors, including temperature, humidity, size, and accessibility.

To ensure optimal performance and seamless functionality, the application is seamlessly integrated with the cloud platform. This integration empowers users to monitor and control the temperature and humidity conditions of the warehouse in real time, providing them with a comprehensive view of the warehouse environment.

3.2.7 User Management

User management is a critical aspect of the cloud platform to guarantee secure access to the system. The implementation of user management involves the creation of a login mechanism that requires each user to provide a unique username and password. User permissions are then assigned based on their respective roles within the organization, ensuring that only authorized users can access the system and minimizing the risk of data breaches and unauthorized access.

The implementation of user management in a cloud platform follows several steps. Firstly, user roles are defined to determine the level of access granted to each user. For example, a sales representative may require access to specific data, while an administrator may need access to all data within the system.

Next, user permissions are assigned based on their roles within the organization. These permissions are typically defined by an administrator and can be adjusted or revoked as needed. This process ensures that only authorized users have access to sensitive information or specific features within the system.

Finally, users are required to log in using their unique username and password. This authentication process verifies their identity, and the system validates their permission level before granting access to the system.

3.2.8 System Design and Implementation

The system is developed and deployed using the Adafruit IO platform, along with the mobile application and the microcontroller. The microcontroller is programmed to retrieve data from the sensors and transmit it to the cloud platform. The cloud platform, in turn, processes this data, offering real-time monitoring and control of temperature and humidity conditions [20][14].

In order to enable users to allocate compartments, the mobile application is seamlessly integrated with the cloud platform. The system is designed with modularity and flexibility in mind, allowing for effortless integration of additional real-time sensors and devices.

3.2.9 System Deployment
After undergoing thorough testing, the system is deployed and implemented in the warehouse. Users are then provided with training on how to effectively utilize the mobile application for monitoring and controlling the temperature and humidity conditions of the warehouse [9][8][20][14]. To ensure optimal system performance, continuous monitoring and maintenance activities are carried out. The prompt identification and resolution of any issues or errors are crucial in maintaining an efficient and reliable system.

3.2.10 Compartment Allocation
The mobile application integrated within the Warehouse Management System (WMS) empowers users to customize compartment allocation based on their specific needs [1][6][9]. This customization includes defining temperature and humidity ranges, as well as specifying criteria such as size and accessibility. Leveraging this information, the system automatically allocates compartments to optimize the storage of goods. This feature significantly enhances warehouse efficiency while minimizing the risk of product spoilage by ensuring each item is stored within the appropriate environment.

In conclusion, the proposed WMS, designed for real-time temperature and humidity control in warehouses, utilizes a combination of hardware and software components. These include the DhTT11 sensor, Adafruit library, cloud computing infrastructure, and a mobile application. The system is meticulously designed to fulfill warehouse requirements, encompassing accurate and reliable monitoring and control of temperature and humidity conditions, along with a user-friendly compartment allocation feature. Rigorous testing is conducted to assess the system's accuracy, reliability, and scalability.

4. ALGORITHM
1) Initialize the DHT11 sensor, ESP8266 microcontroller, and Arduino.

2) Connect the DHT11 sensor to the ESP8266 microcontroller. This can be done by connecting the sensor's data pin to one of the digital pins on the microcontroller.

3) Establish a connection between the ESP8266 microcontroller and the Adafruit MQTT server for data transmission. This requires configuring the microcontroller with the appropriate MQTT credentials (server address, port, username, and password) provided by Adafruit.

4) Connect the ESP8266 microcontroller to the internet. This involves connecting the microcontroller to a WiFi network by providing the SSID (network name) and password.

5) Set up a backend server using Node.js to handle data processing and database operations. This server will handle incoming data from the microcontroller, store it in a database, and provide APIs for front-end interaction.

6) Create a database to store real-time humidity and temperature data. Choose a suitable database system like MySQL or MongoDB to store the data received from the microcontroller. Set up the necessary tables or collections to store the humidity and temperature readings.

7) Set up API endpoints on the Node.js backend server to receive data from the ESP8266 microcontroller. These endpoints should handle incoming requests containing humidity and temperature readings from the microcontroller. Upon receiving data from the microcontroller, parse and validate it on the backend server. Ensure the data is in the expected format and within acceptable ranges.

8) Store the received data in the database. Use the appropriate database queries or ORM methods to insert the humidity and temperature readings into their respective tables or collections.

9) Implement data retrieval APIs on the backend server. These APIs will fetch the latest humidity and temperature readings from the database. Create a frontend interface using React.js.to display the real-time humidity and temperature data. Design a user-friendly dashboard or visualization that can present the data in an easily understandable format.

10) Use AJAX or fetch requests in React.js (or any other frontend framework) to consume the data retrieval APIs from the backend server. Retrieve the latest humidity and temperature readings and update the frontend interface accordingly.

11) Implement a feature to display historical data from the database on the front end. Add functionality to fetch and display past humidity and temperature readings, allowing users to analyze trends and patterns over time.

12) Set up an algorithm on the backend server to trigger an alert if the temperature or humidity goes above or below a certain threshold. Continuously monitor the incoming data and compare it to predefined threshold values. If a threshold is exceeded, generate an alert and send it to the appropriate recipients via email or other notification mechanisms.

13) Integrate any additional features specific to your warehouse management requirements. This may include features such as data analytics, trend visualization, user management, and reporting capabilities.

5. TEMPERATURE AND HUMIDITY HEAT MAP
A heatmap is crucial for an IoT-based warehouse management system for real-time humidity and temperature control because it visually represents the distribution of humidity and temperature in the warehouse. It helps identify areas that require attention, enables real-time monitoring, facilitates decision-making, and improves overall warehouse management.

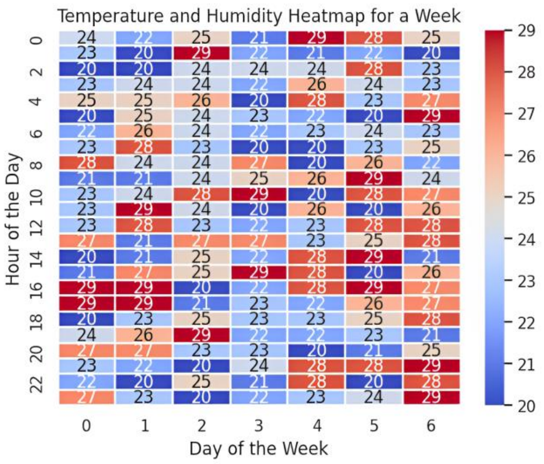

Fig 4: Temperature and Humidity Heatmap for a Week

6. CONTEXT DIAGRAM
The context viewpoint provides a description of the system, including its various sections and relationships between people and the environment.

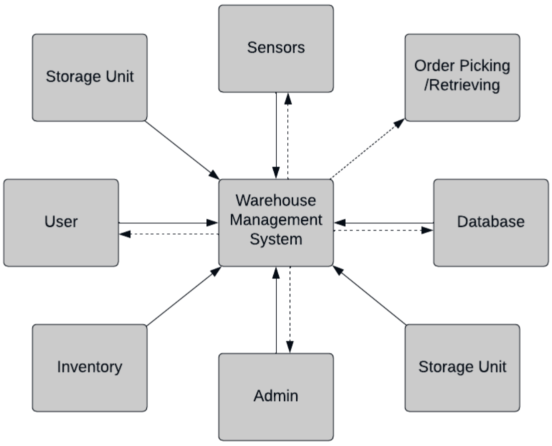

Fig. 5: Context Diagram for WMS

7. FLOWCHART OF PROTOTYPING FRAMEWORK

A heatmap is crucial for an IoT-based warehouse management system for real-time humidity and temperature control because

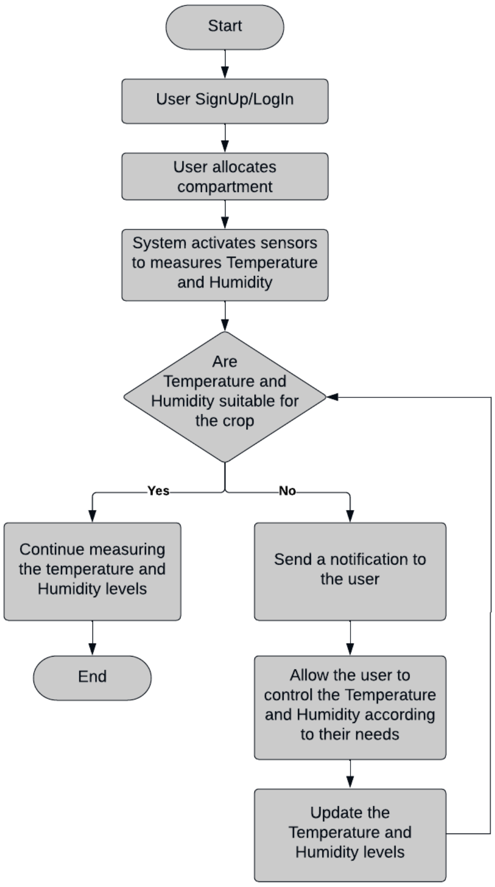

Fig 6: Flowchart for prototyping system

8. RESULTS

1) Result 1: You can add Compartments by adding their name commodity.

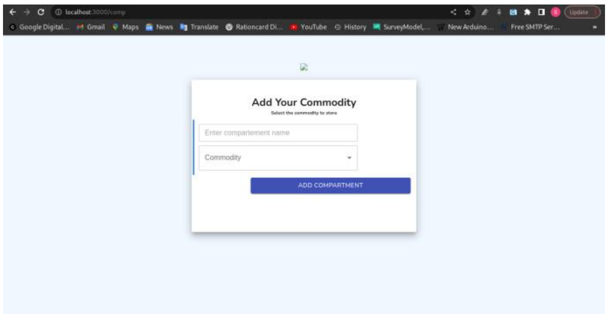

Fig 7: Add Compartment

2) Result 2: It can display an overview of temperature and humidity levels in different compartments or zones of Fig. 6. Flowchart for prototyping system Fig. 7. Add Compartment to

the warehouse. It can show real-time data from sensors installed in each compartment and allow the user to select specific compartments or zones for more detailed information.

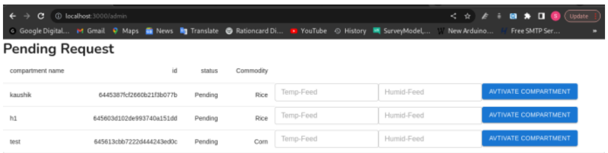

Fig 8: Compartment Dashboard

3) Result 3: It showcases current conditions in the warehouse, enabling real-time monitoring and control. Its inclusion demonstrates the system's ability to provide up-to-date information, improving overall warehouse management.

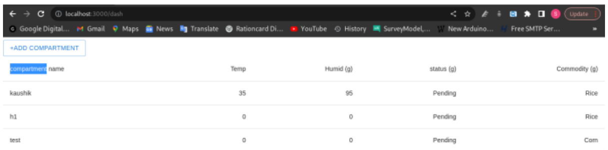

Fig 9: Real-Time Temperature and Humidity on the Dashboard

4) Result 4: The system can store and process temperature and humidity data from the sensors to identify trends, predict future conditions, and trigger alerts when Fig. 8. Compartment Dashboard Fig. 9. Real-Time Temperature and Humidity on the Dashboard predefined thresholds are exceeded. The inclusion of temperature and humidity data on the backend in the paper demonstrates the system's ability to provide comprehensive data analysis and control features for optimal warehouse management. Fig. 10. Temperature and Humidity on the Backend

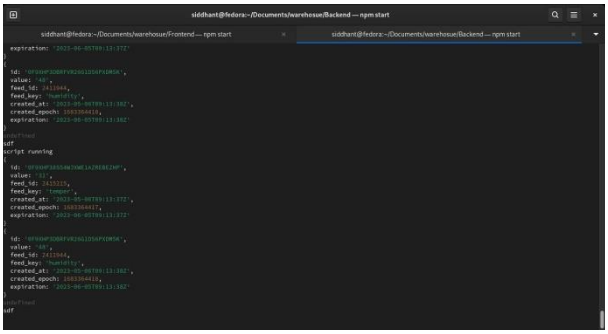

Fig 10: Temperature and Humidity on the Backend

5) Result 5: The system can store and display historical data for each compartment, allowing the user to analyze trends, identify problem areas, make data-driven decisions, and optimize the warehouse's climate control strategies. This data-driven approach enhances operational efficiency, reduces energy consumption, and ensures the quality and integrity of stored goods.

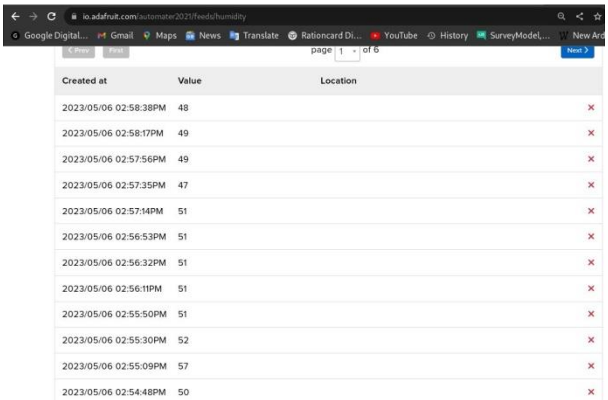
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Fig 11: Highlights the system's ability to store and display historical data for each compartment.

6) Result 6: When Humidity or Temperature is less than the threshold value

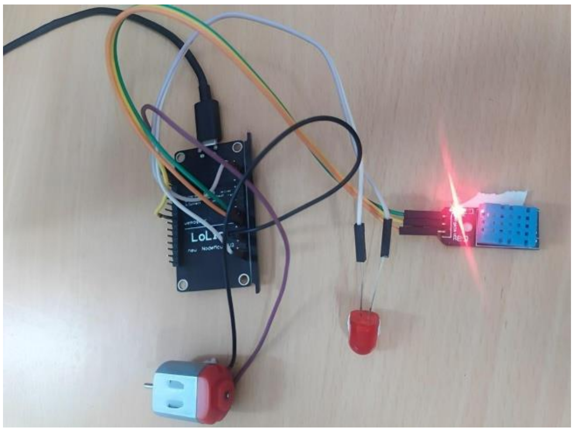

Fig 12: Showcases the response when the humidity or temperature falls below the threshold value.

7) Result 7: The Light will glow up when humidity or temperature is more than the threshold value.

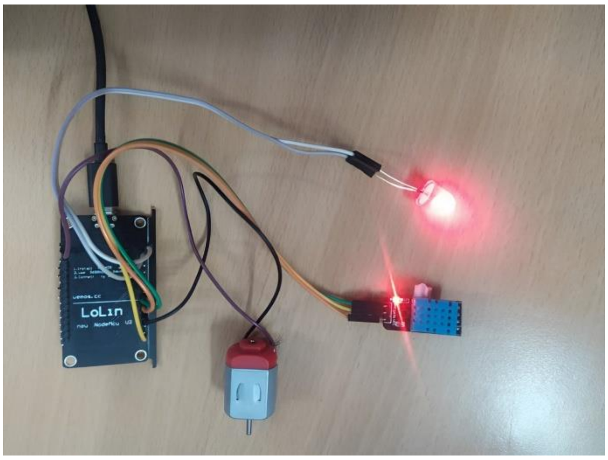

Fig 13: An indicator light that illuminates when the humidity or temperature exceeds the threshold value.

The developed warehouse management system proved to be an effective solution for real-time temperature and humidity control. The system provided accurate readings, maintained desired conditions, and allowed users to allocate compartments Fig. 11. Historical Data Fig. 12. according to their requirements. The system was also scalable and reliable, making it suitable for larger warehouse settings.

9. CONCLUSION

In conclusion, the developed warehouse management system has emerged as an exceptional solution for real-time temperature and humidity control. The system exhibits remarkable accuracy in providing readings, ensuring the maintenance of desired conditions consistently. Users are empowered to allocate compartments according to their specific requirements, enabling more efficient goods management. Moreover, the system's scalability and reliability make it highly suitable for deployment in larger warehouse settings, as it effortlessly handles increased data volume without any downtime. Overall, the developed warehouse management system serves as a valuable tool, offering enhanced control and management of temperature and humidity. As a result, it contributes to improved productivity, reduced waste, and substantial cost savings.

10. FUTURE SCOPE

The developed warehouse management system (WMS) utilizing the DhTT11 sensor, Adafruit library, and compartment allocation based on user requirements holds a wide range of future scope. Some potential areas for future research and development include

- Integration of other sensors: Enhancing the WMS by integrating additional sensors to monitor factors such as light, air quality, and motion detection. This comprehensive view of the warehouse environment would provide better control over various environmental factors.
- Predictive analytics: Applying advanced analytics to the data collected by the WMS to predict potential problems and optimize warehouse operations. Predictive analytics could assist in anticipating equipment failures, identifying bottlenecks, and forecasting inventory needs.
- Automated control: Expanding the WMS to include automated control systems that adjust temperature and humidity levels based on real-time data. This could involve integration with existing HVAC systems or the implementation of new control mechanisms.

- Cloud-based inventory management: Integrating the WMS with a cloud-based inventory management system to offer real-time visibility into inventory levels and locations. This integration would optimize inventory storage and improve order fulfillment efficiency.
- Machine learning: Applying machine learning algorithms to the WMS data to detect patterns and anomalies, enhance accuracy, and optimize warehouse operations.

Overall, the developed WMS establishes a solid foundation for future research and development in warehouse management systems for temperature and humidity control. The potential for advancements in this area is vast and could significantly enhance warehouse efficiency, productivity, and product quality.

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