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Implementation of IoT-based Flexible Temperature and Humidity Monitoring in Inventory and Transportation of Sensitive Goods

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Abstract

The implementation of IoT has become a standard approach for developing solutions across various industrial automation systems. In supply chain management and logistics, reducing waste and ensuring efficient information flow through real-time monitoring are essential for maintaining smooth and lean operations. This study focuses on two critical components of the supply chain—inventory management and transportation—and presents a flexible temperature and humidity monitoring system capable of both continuous observation and adjustable threshold control based on operational needs. The system integrates an ESP8266 NodeMCU module, a DHT11 temperature and humidity sensor, a GPS module for transportation data, and an I2C LCD for local display. Its primary goal is to prevent losses caused by inadequate environmental oversight and to provide decision-makers with greater authority and responsiveness in managing sensitive goods. As demonstrated through the experimental setup and results, the system delivers real-time data visualization, user-controlled threshold settings via a slider interface, and reliable temperature and humidity streaming. These capabilities make the system adaptable for dynamic logistics environments, offering a practical solution for reducing waste related to improper storage conditions, such as spoiled perishable foods or degraded pharmaceutical products. In future implementations, coupling this monitoring system with HVAC units could further enhance environmental control during both inventory storage and transportation. Moreover, the collected data can support informed decision-making, helping organizations plan proactively and optimize their operations.

Keywords
IoT, Dynamic inventory, NodeMCU, DHT 11 Sensor, sensitive goods.

1.1 Introduction
Transportation and inventory are core components at every level of the supply chain. In lean terms, these two components often create many sources of waste. For instance, lack of proper monitoring, real-time information,

flow of elements and goods, bottleneck neck etc. Waste that is caused during inventory and transportation due to a lack of proper real-time monitoring is a common phenomenon. A recent research on cold supply chain addresses the global challenge of food waste in supply chains, emphasizing the critical role of temperature control in cold chain logistics. It reviews advanced technologies like RF, WSN, neural networks, CFD, and thermal imaging, highlighting their strengths and limitations. The research advocates for an integrated IoT-based approach to enhance data exchange and monitoring, acknowledging that no single solution fits all due to diverse product and transport variables. Combining these technologies offers the most promising path to improving food safety, reducing waste, and strengthening supply chain resilience (Badia-Melis et al., 2018). Another study reviews 59 studies on IoT sensor technologies for reducing food loss and waste (FLW) in supply chains, highlighting frequent use in monitoring fruits and vegetables. It emphasizes the vast potential of IoT to enhance food quality, logistics, and sustainability across regions and supply chain stages (da Costa et al., 2023). Nowadays, the operations of logistics-based teams are getting more dynamic. For instance, a logistics company that works for the inventory and transportation of multiple types of products often finds it difficult to monitor temperature and humidity in real time. Additionally, this also exacerbates the problem where inventory and transportation are not utilized interchangeably. As transportation and inventory happen almost every step in the supply chain, it is really crucial to minimize waste due lack of monitoring of temperature (Figure 1).

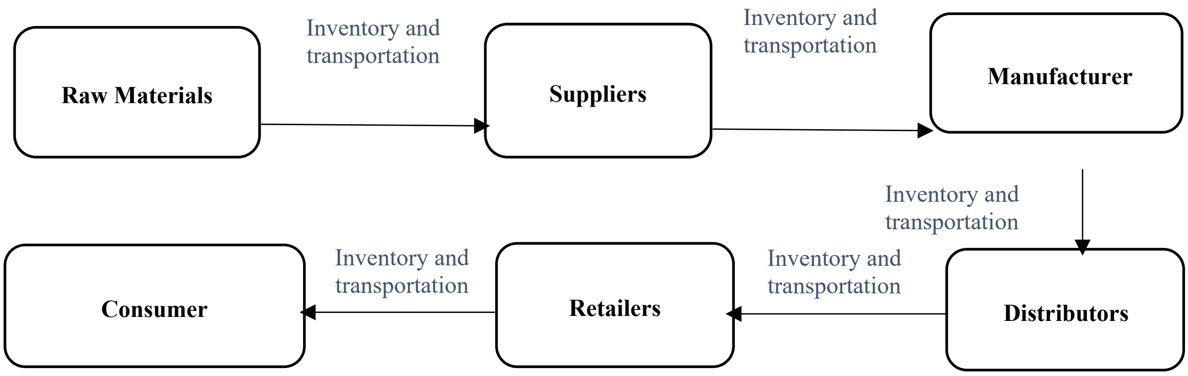

Figure 1. Inventory and transportation in all steps of the supply chain.

Addressing the importance of real-time monitoring, in this study, an IoT-based flexible temperature and humidity monitoring system using an ESP8266 wifi module, DHT11 temperature and humidity sensor, GPS module, and I2C LCD has been formulated for logistic-based real-time operation of any type of sensitive goods, eg, Food, pharmaceuticals, and any FMCG products. In this setup, the authority can change the range and threshold of their desired temperature and humidity according to their goods, which give them flexibility to use the same transportation and inventory for various goods for a certain range of storing temperature. Because of the GPS module, the authority can also track the location especially for the transportation parameters like distance, route etc., by which they can take future action for the remedy of any waste associated with this concern. This study aims to design and implement a flexible IoT-based temperature and humidity monitoring system for inventory and transportation processes in supply chain operations. The objective is to minimize waste and improve decision-making by enabling real-time environmental tracking and customizable threshold control for sensitive goods.

2. Literature Review

IoT has proven as one of the most reliable solutions in various divisions of industries, a proven methodology for any cloud-based real-time monitoring solution. The purpose of IoT is to enable real-time data collection, monitoring, and control by connecting physical devices to the internet. It enhances automation, decision-making, and efficiency across industries such as healthcare, agriculture, logistics, and smart cities. As this study is focusing on formulating a flexible setup of temperature and humidity monitoring for the part of the supply chain where inventory and transportation are the main concern, this literature has discussed relevant studies where IoT-based tools are utilized to solve similar problems.

A study on IoT-based wireless temperature monitoring in fruit and vegetable supply chains enables predictive shelf-life modeling and waste reduction, but faces technical, operational, and sustainability challenges requiring tailored solutions. The study identified key requirements—such as ≥3–4 week battery life, <2% data loss, and ≤10 min intervals—validated through real-world testing (Lamberty & Kreyenschmidt, 2025). A qualitative study on Finnish pharmaceutical cold chains found that IoT-based temperature monitoring improves regulatory compliance, reduces waste, and supports sustainability, though SMEs face adoption barriers requiring phased implementation and collaboration (Buzuleeva, 2025). A BLE-based real-time monitoring system using nRF52840 and Zephyr RTOS offers energy-efficient temperature control for cold chains, integrating a PID-controlled Peltier module and an Android app for visualization. With a COP of 2.1 and no reliance on Wi-Fi or cellular networks, it provides a compact, cost-effective solution for transporting temperature-sensitive goods like vaccines(Gangarapu & Prithvi, 2025). A recent study on the aims of IoF2020 enables large-scale IoT deployment in meat supply chains to improve traceability, safety, and efficiency. Smart sensors and alert systems support real-time monitoring, while EPCIS and HACCP ensure farm-to-fork transparency (Kolikipogu et al., 2025). A study by (Kolikipogu et al., 2025) IoT integration in cold chain logistics enables real-time monitoring of temperature-sensitive goods, reducing spoilage and improving safety. Despite its potential, current solutions often focus narrowly on temperature, overlooking other critical factors like humidity and CO_2, which this paper aims to address through smart, cloud-based systems. (Hemakesavulu et al., 2025) shows an IoT-based preservative system powered by solar energy that monitors food spoilage in real-time using sensors for temperature, humidity, gas, and pH. It ensures food safety and reduces waste by providing alerts and remote updates via GSM and ThingSpeak. Another study proposes a blockchain-powered DApp for monitoring cargo in heavy goods vehicles, enhancing cold-chain reliability beyond temperature control. It integrates Ropsten testnet with cloud platforms, uses Firestore for routine data, and recommends Layer-2 scaling and self-hosted nodes to improve efficiency and reduce costs (Gokulanathan, 2025). Another relevant study presents a systematic literature review of IoT applications in food processing from 2011 to 2024, covering domains like safety, packaging, traceability, supply chain, and waste. It proposes an IoT architecture based on reviewed studies to enhance monitoring and communication across food sectors (Alimadani et al., 2025). A recent study (Sampathrajan et al., 2025) presents an IoT and XGBoost-based temperature control system for pharmaceutical manufacturing, enabling real-time monitoring and predictive analytics. The approach enhances temperature stability, reduces product degradation, and ensures compliance with industry standards. A study introduces an IoT and ML-based system for real-time meat quality monitoring in Nepal, using gas, temperature, and humidity sensors. It highlights significant spoilage rates, especially in fish, and offers a scalable, data-driven solution to improve food safety in resource-limited settings (Pantha et al., 2025).

The general use of ESP8266 or ESP32 and DHT11 or DHT22 temperature and humidity sensors in providing modern IoT-based solutions is abundant. A project of (Raj et al., 2025) uses an ESP32 Node MCU and DHT11 sensor to monitor and stream temperature and humidity data from an FDM 3D printer to the ThingSpeak platform. It offers a practical guide for beginners to implement real-time IoT-based environmental monitoring via cloud communication. Another study developed an IoT-based AC control system using NodeMCU ESP8266, DHT11, and PIR sensors to automate temperature and occupancy-based adjustments. It achieved stable room conditions, energy savings, and user satisfaction, supporting smart classroom goals with plans for sensor upgrades and voice integration (Aswandi et al., 2025). Another relevant study introduces an IoT-based calorimeter using ESP8266 and Blynk for real-time heat transfer measurement, enhancing accuracy and usability. It significantly improves physics education and research, with liquid temperature shown to impact results more than solid type (Hafiz et al., 2025). A study on ESP8266 demonstrates remote actuator control using the Internet by integrating ESP8266 with Arduino Uno. Devices are connected, programmed, and tested to enable long-distance operation of electrical systems, addressing key IoT challenges in connectivity and automation (Ahmedi & Mustafa, 2026). A study of (Ahmedi & Mustafa, 2026) develops an IoT-based temperature monitoring system using ESP8266 and DS18B20 sensors, integrated with Blynk and Telegram for real-time alerts and data logging. It enhances vaccine cold chain management by automating monitoring and reducing manual recording, supporting pharmaceutical safety and efficiency.

There are a plausible number of studies discussing the importance of maintaining optimal temperature and humidity at different levels of the supply chain. A project of (V. et al., 2025) integrates climate and meteorological data into pharmaceutical logistics to optimize storage, transit, and restocking of temperature-sensitive drugs. It proactively adjusts supply chain operations to mitigate weather-related disruptions, enhancing reliability and safety. Another study demonstrates how integrating IoT, AI, and data analytics can optimize urban waste management by reducing inefficiencies in supply chains. Using a case study and machine learning, it highlights how digital tools enhance sustainability, align with circular economy goals, and support smart city resilience (Fatorachian et al., 2025).

The primary significance of this study lies in presenting a versatile and practical solution for monitoring temperature and humidity across two critical stages of the supply chain: inventory and transportation. Although numerous existing studies offer industry-level approaches to similar challenges, this work addresses a specific real-world problem frequently faced by logistics companies—maintaining environmental conditions for sensitive goods throughout their journey. By integrating IoT-based monitoring into both stationary and mobile contexts, the study provides a more adaptable and responsive approach than many traditional systems. The results obtained from the prototype and testing phases further demonstrate the effectiveness, reliability, and real-world relevance of the proposed application.

3. Methodology

3.1 Experimental Setup

To demonstrate the functionality and results of the proposed IoT-based design, a complete experimental setup was developed. The system incorporates an ESP8266 Wi-Fi module as the microcontroller, a DHT11 sensor for measuring temperature and humidity, a 16×2 I2C LCD for displaying real-time data, a GPS module for location tracking, and a 3.7V Li-Po battery to provide portable power. Figure 2 presents the physical layout and assembled components of the prototype, offering a visual overview of the hardware configuration. Figure 3 illustrates the corresponding circuit diagram, showing how each module is interconnected within the system. This setup serves as a practical validation of the design's feasibility and performance.

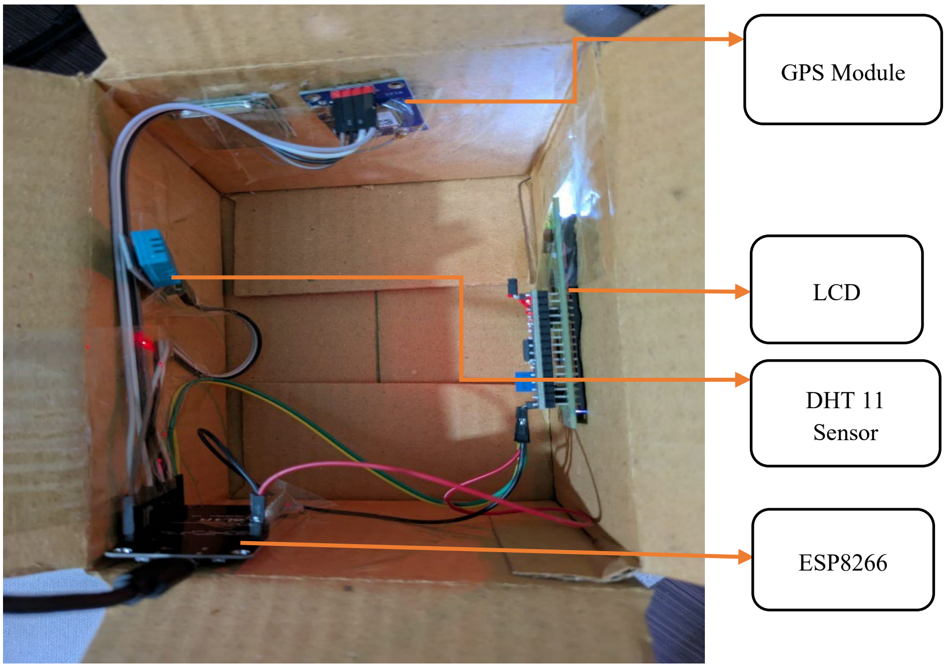

Figure 2. Experimental setup for Felsinle temperature and humidity monitoring.

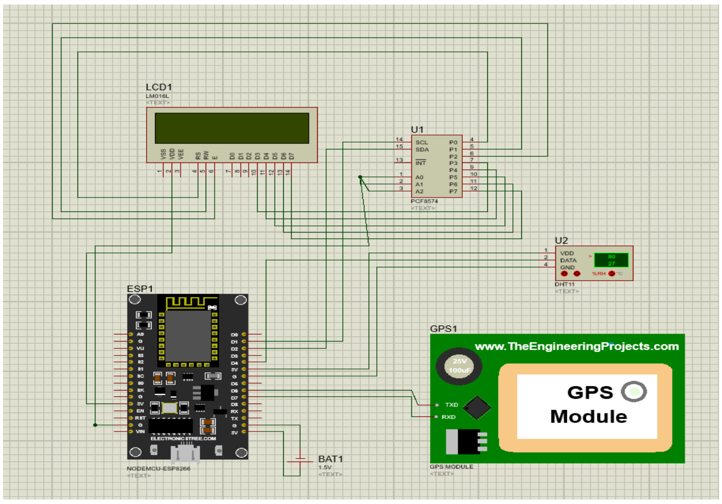

Figure 3. Circuit diagram of the experimental setup.

Figure 4 shows the operation and flow of information of IoT-based flexible temperature and humidity measuring system.

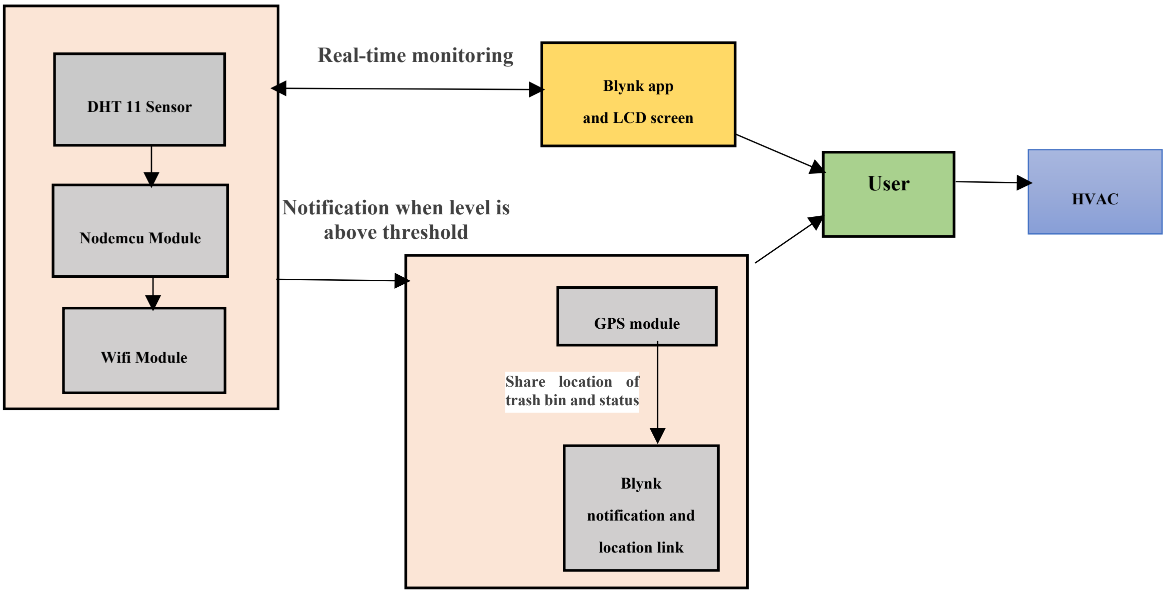

Figure 4. Workflow diagram of proposed experimental setup.

Algorithm 1: IoT based flexible temperature and humidity monitoring system for Inventory abd transportation in supply chain.

1. Initialize hardware
- Define Blynk credentials (ID, Name, Token)
- Include libraries: ESP8266WiFi, BlynkSimpleEsp8266, DHT, Wire, LiquidCrystal_I2C, SoftwareSerial, TinyGPS++
- SET DHTPIN = D4, DHTTYPE = DHT11
- INIT DHT sensor, LCD (0x27, 16x2), custom icons (fire, drop)
- START Serial at 115200, turn on LCD backlight
- CONNECT to Wi-Fi + Blynk, SYNC V2 (maxTemp), V3 (maxHum)

2. Setup timer
- CALL sendSensorData() every 2 seconds

3. LOOP FOREVER
- RUN Blynk service
- RUN timer

4. Function: sendSensorData()
- READ temp, hum FROM DHT
- CLEAR LCD
- IF invalid THEN
  DISPLAY "Sensor Error!" / "Check DHT11"
  RETURN
- DISPLAY "T:<temp>°C" on line 1
- DISPLAY "H:<hum>%" on line 2
- SEND temp → V0, hum → V1
- FETCH GPS location
  IF valid → append lat/lon
  ELSE → "GPS Fixing..."
- **IF** temp ≥ maxTemp THEN

LOG "High Temp" with GPS
SHOW fire icon at (10,0)
- **IF** hum ≥ maxHum THEN
LOG "High Humidity" with GPS
SHOW drop icon at (10,1)

END

1.2 Application in Transportation and Inventory

In the transportation of goods, logistics operations that use the same vehicle to deliver different types of products can adjust temperature and humidity settings based on each item's specific requirements. This flexibility is especially important when transporting sensitive goods that must remain within certain environmental conditions. As shown in Figure 5, the system continuously monitors the temperature, sends alerts when readings exceed the defined threshold, and allows adjustments to be made during both transport and temporary inventory stages. By enabling real-time control and rapid response, this IoT-based system makes the transportation process more dynamic, efficient, and better suited for handling a wide variety of goods.

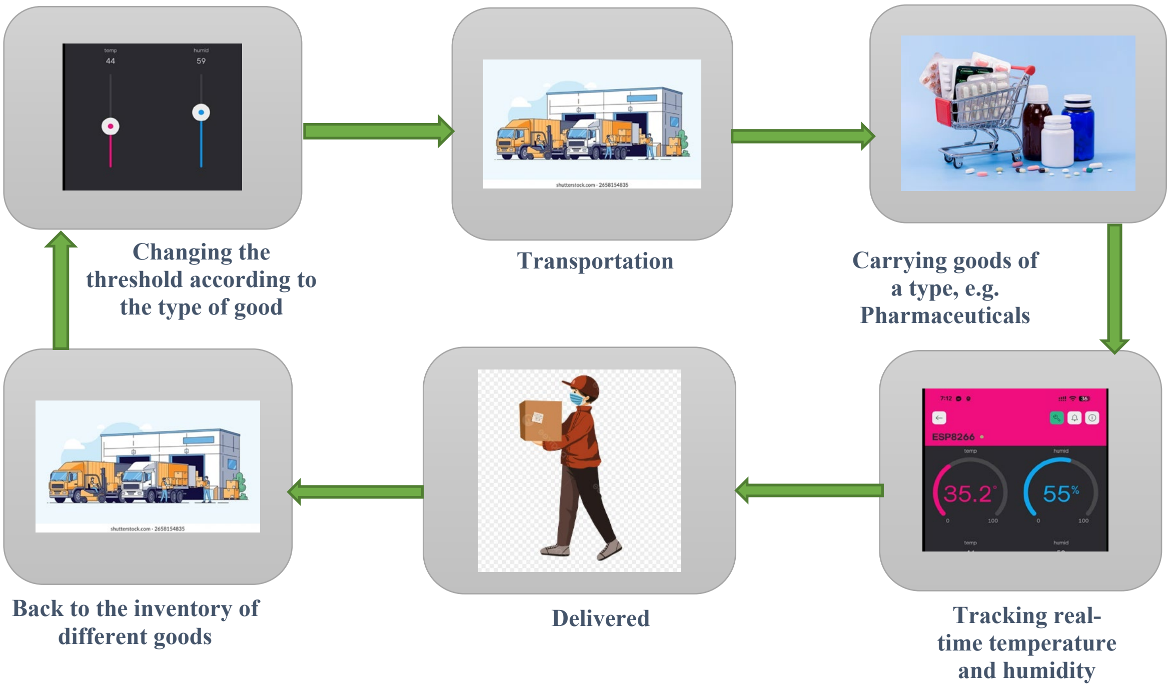

Figure 5. Utilizing IoT-based Temperature and Humidity monitoring during

During inventory management, temperature and humidity can be adjusted and monitored to support a dynamic inventory system. Since goods often remain in warehouses for long periods, especially sensitive items that can degrade under poor environmental conditions, continuous monitoring is essential. Throughout stages like storage and cross-docking, IoT-based systems provide real-time data and alerts, ensuring conditions stay within safe limits. This control also allows facilities to store different types of goods at different times by adjusting conditions as needed. Figure 6 shows the overall steps of how the IoT-based temperature and humidity system helps maintain and regulate these conditions.

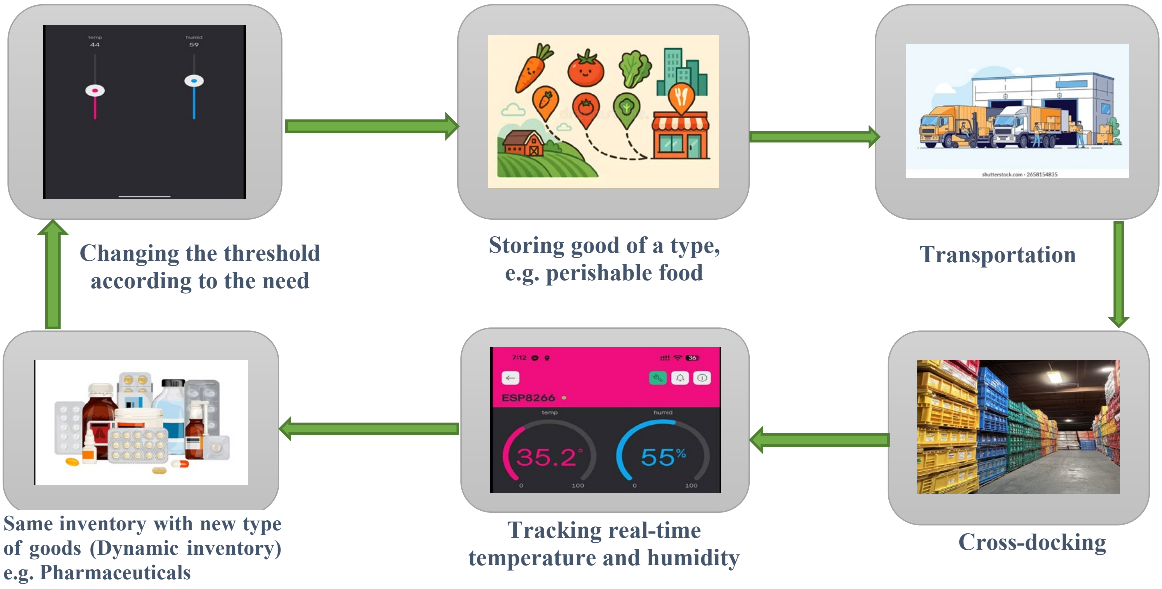

Figure 6. Utilizing IoT-based Temperature and Humidity monitoring during inventory.

2. Results

This section presents the results obtained from the experimental setup using the Blynk application. The platform showcases the final objectives of the system, allowing users to fully interact with the monitoring process. Through the app, users can adjust and customize their threshold limits for temperature and humidity based on the specific requirements of different goods. They can also monitor real-time environmental data along with the current location of the shipment, ensuring complete visibility during both inventory and transportation. Additionally, the system provides access to a continuous data stream, enabling users to view historical records, analyze trends, and make more informed decisions regarding storage and transport conditions. This comprehensive set of features demonstrates the practicality and effectiveness of the IoT-based solution.

2.1Blynk-app Results

The figure presents the overall monitoring results of the system. Figure (a) displays the real-time measurements of temperature in degrees Celsius and humidity in percentage, demonstrating how the system continuously updates environmental data. It also illustrates the user's ability to adjust the temperature and humidity threshold limits based on specific requirements during both inventory storage and transportation. Figure 7 (b) presents the alert notifications generated for both temperature and humidity, along with the corresponding longitude and latitude coordinates for real-time location tracking during transportation. These notifications allow users to immediately identify when environmental conditions move beyond acceptable limits while also providing precise positional data of the goods in transit. The inclusion of location information not only enhances traceability but also enables further analysis, such as calculating travel distance or correlating environmental changes with specific points along the route. This integrated alert and tracking system strengthens overall monitoring and supports more informed decision-making during transportation. Figure 8 shows the live data stream for temperature and humidity. Figure 9 shows the real time monitoring on the LCD.

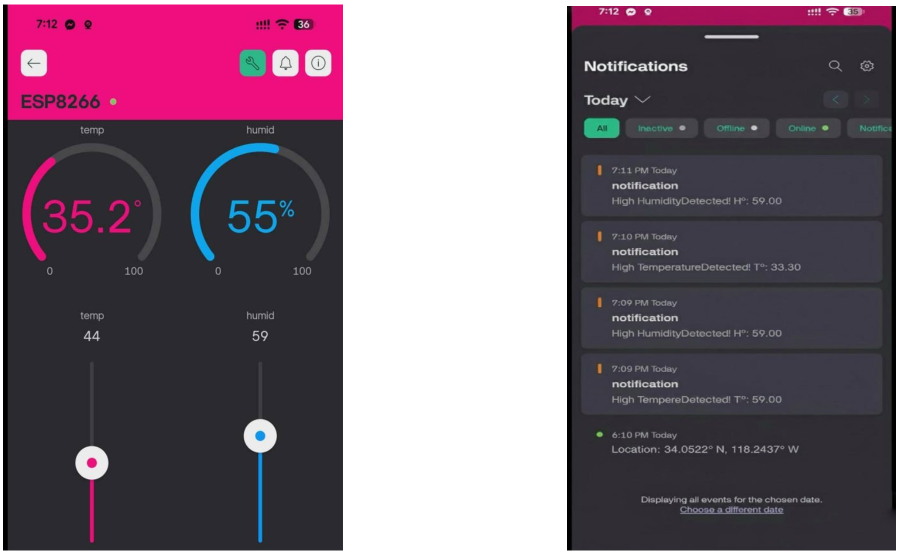

Figure 7. Blynk-app result for threshold adjuster, monitoring and alert.

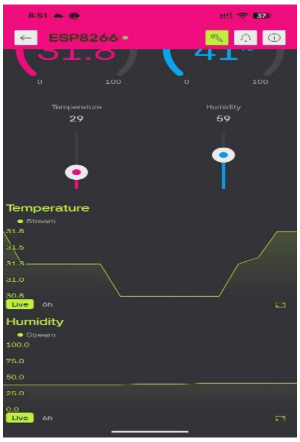

Figure 8. Blynk app result with data stream for temperature and humidity.

Figure 9. 16X2 I2C LCD for displaying real-time temperature and humidity.

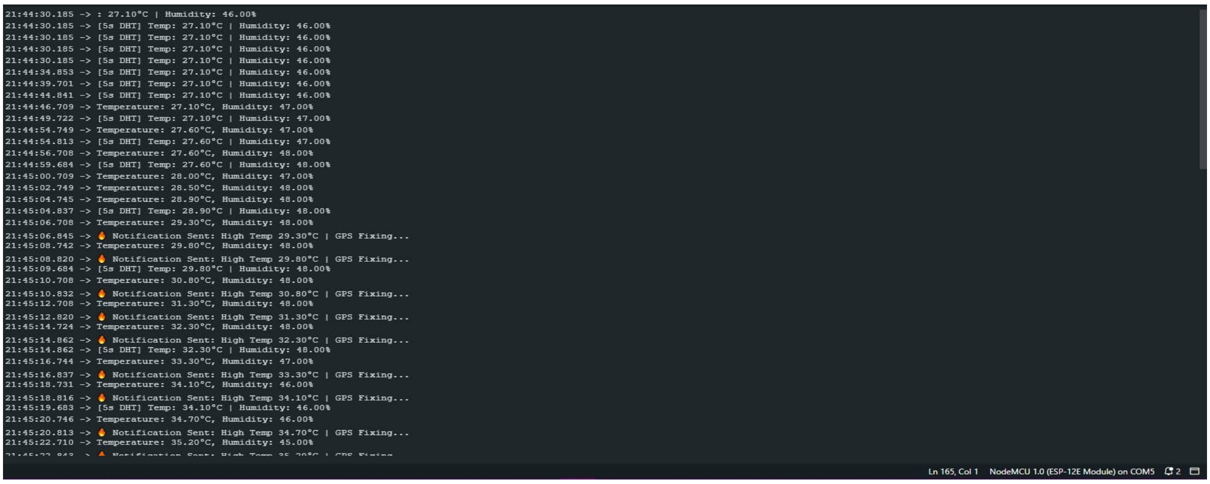

Figure 10. Arduino Serial COM results fot temperature and Humidity.

Table 1 presents several existing studies in which IoT-based temperature and humidity monitoring has been implemented, including applications across various sectors of the supply chain.

Table 1. Comparison with existing work

IoT in Temp and Humitity	Temp and humid monitoring in supply chain	Dynamic temperature and humidity monitoring solution	References
✓	✓	×	(Kolikipogu et al., 2025)
✓	×	×	(Hemakesavulu et al., 2025)
✓	✓	×	(Alimadani et al., 2025)
✓	×	×	(Sampathrajan et al., 2025)
✓	×	×	(Pantha et al., 2025)
✓	×	×	(Ahmedi & Mustafa, 2026)
✓	×	×	(V. et al., 2025)
✓	✓	✓	This work

3 Conclusion

This study demonstrates the practical value and effectiveness of an IoT-based temperature and humidity monitoring system for improving supply chain operations across both inventory management and transportation. By integrating an ESP8266 NodeMCU, a DHT11 sensor, a GPS module, and an I2C LCD, the system successfully provides continuous real-time environmental data along with adjustable threshold control, enabling users to tailor monitoring conditions to the specific requirements of different goods. The experimental results offer relevant insights into how such a system performs in both stationary inventory settings and dynamic transportation environments, highlighting its flexibility and reliability. These findings suggest that the system can significantly reduce losses associated with poor environmental oversight, particularly for perishable or temperature-sensitive products, while also enhancing operational transparency and control. Furthermore, the availability of real-time and historical data supports more informed decision-making, allowing authorities to respond proactively to potential disruptions. With future integration into HVAC systems, the monitoring solution can achieve even more precise temperature and humidity regulation, strengthening its potential to optimize logistics efficiency, minimize waste, and contribute to more resilient supply chain practices. The limitation of DHT 11 temperature sensor is it can only measure temperature from 0 to 50 degree celcius while using sensor such as DS18B20 or SHT3x can overcome this limitation. In future this study can be extended by implementing MCDM where the opinion of experts will be analysed.

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