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IoT-Based Real-Time Monitoring System for Temperature and Humidity Control in Pharmaceutical Manufacturing

Khandve Pranjal Mahendra[1,*], Kolhe Payal Ganpat[1], Kshirsagar Vedant Umesh[1], Lokhande Sai Sunil[1], Naveen Kumar[2]

Abstract

Environmental conditions, especially temperature and humidity, play a vital role in pharmaceutical manufacturing processes. Even minor fluctuations in these parameters can significantly influence the stability, potency, and overall effectiveness of drug formulations. In many cases, uncontrolled environmental variations may lead to chemical degradation, reduced shelf life, contamination risks, and substantial financial losses for manufacturers. Therefore, maintaining precise and consistent environmental conditions is essential to ensure product quality, regulatory compliance, and patient safety. To overcome these challenges, an Internet of Things (IoT) based real-time monitoring system has been designed to continuously observe and regulate temperature and humidity levels within pharmaceutical production facilities. The proposed system incorporates DHT22 sensors to accurately measure environmental conditions and an ESP32 microcontroller to process, analyze, and transmit the collected data. The processed information is displayed through a user-friendly mobile application developed using MIT App Inventor, allowing operators to monitor real-time readings remotely and conveniently. Additionally, the system is programmed with predefined safety thresholds. Whenever the measured temperature or humidity values exceed acceptable limits, immediate alerts are generated to notify responsible personnel. This enables prompt corrective actions to prevent product damage and maintain optimal manufacturing conditions. Overall, this smart monitoring solution improves quality assurance, minimizes product wastage, enhances operational efficiency, and offers a reliable, affordable approach to environmental control in pharmaceutical industries.

Keywords: DHT22 sensor, drug stability, ESP32, humidity monitoring, IoT, MIT App Inventor, pharmaceutical manufacturing, quality assurance, real-time monitoring, temperature control

INTRODUCTION

Pharmaceutical industries constantly incur millions in financial losses due to spoilage from temperature changes, potential patient trouble, and secure actions. Most biologic products are produced by pharmaceutical companies and are highly sensitive to storage conditions [1–5]. Certain medications must be maintained at a consistent temperature by adhering to cold chain procedures, whether in storage or transit. Biological products, which have a limited shelf life and strict temperature requirements, are largely composed of high-value active ingredients. Cold storage, cold storage, and cold transport are the three components of cold chain operations [6–9]. These medications must be transported in temperature-controlled containers, such as reefers, to avoid spikes in ambient temperatures. The Internet of Things (IoT) is one framework that facilitates application design [10–16].

***Author for Correspondence**
Khandve Pranjal Mahendra
E-mail: pranjalkhandve52@gmail.com

[1]Student, Department of Mechatronics Engineering, Sanjivani College of Engineering, Kopargaon, Maharashtra, India
[2]Assistant Professor, Department of Mechatronics Engineering, Sanjivani College of Engineering, Kopargaon, Maharashtra, India

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Several researchers have played a significant role in developing IoT-based real-time systems. They presented a model in which sensors were installed to monitor variables such as temperature and humidity, and data were collected using an IDE (integrated development environment) [17]. The web interface receives the outcome evaluation via Wi-Fi. Every step of the detection process was managed by an ATmega 328 controller. Additionally, this controller stores the sensor data and transmits it to clients through the cloud. Tiwari et al. suggested a wireless and Internet of Things-based approach for weather monitoring [18]. They developed a systematic framework for transferring data to cloud computing services using an Arduino UNO board, sensors, and a Wi-Fi module. The introduction of a stability chamber model is an important tool in pharmaceutical facilities [19]. It stores products under different environmental conditions for a set time to evaluate their quality and stability.

In this project, we successfully developed a real-time temperature and humidity monitoring system that detects changes in parameters in the pharmaceutical industry. In the event of unusual conditions, the system immediately sends security alerts. These alerts are sent via SMS, email, or mobile applications to facilitate immediate decisions. Real-time data, such as temperature and humidity, can be detected and displayed on screens available in mobile applications. In addition, displays on LCD/LED screens or control panels allow workers to quickly see the current conditions and take action to ensure perfect production and storage conditions. This project helps protect the quality of pharmaceutical products and provides more safety. The main goal of this system is to promote increased guarantees and industrial safety. Encourage self-operating pharmaceutical industries to improve product quality and provide security in weather conditions.

METHODOLOGY

This project aims to determine real-time temperature and humidity parameters in drug manufacturing using IoT technology [20–23]. The components required for this setup were a DHT22 sensor, an ESP32 microcontroller, a breadboard, jumper wires, and a tripod stand. Here in Figure 1, the overall flow of the system is shown. In Figure 2, a tripod stand (which provides physical support to the system) is shown.

Microcontroller

The microcontroller used here is the ESP32, which is the processing unit of the system. It takes data from the DHT22 (temperature and humidity) sensor, processes the data, and then sends it to the cloud platform via Wi-Fi.

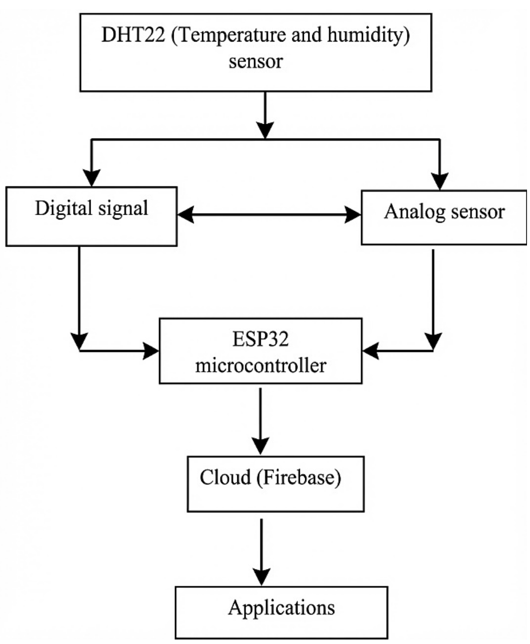

Figure 1. Block diagram.

Figure 2. Tripod stand.

Sensor

The DHT22 sensor was used to measure the temperature and humidity of the drugs. It was specifically chosen for its high accuracy and stability, which are critical in pharmaceutical environments. The sensor connections were configured as follows:

VCC: Connected to a 5.5 V power supply
Data: Connected to GPIO pin 16 on the ESP32
GND: Connected to the ground terminal

Wireless Communication

After processing, the ESP32 sends the sensor data wirelessly to the Firebase cloud platform using Wi-Fi. This enables centralized data storage and remote monitoring.

Real-Time Monitoring Via Mobile Application

For real-time visualization, the system was interfaced with a mobile application developed using the MIT App Inventor. This application displays live temperature and humidity values, facilitating immediate decision-making and environmental control.

Jumper Wires and Breadboard

Jumper wires were used to establish connections between various components, such as the ESP32, DHT22, and power lines. All components were mounted on a breadboard, which also acted as a distribution hub for the power supply [24, 25].

Tripod Stand

A tripod stand (Figure 2) was used to provide an adjustable and stable platform for the system, ensuring optimal positioning for accurate sensing.

RESULT

The developed IoT-based real-time monitoring system was successfully implemented to oversee and control environmental conditions, specifically temperature and humidity, which are critical to pharmaceutical manufacturing and storage processes. The system demonstrated reliable performance in acquiring, transmitting, and displaying the sensor data in real time.

The integration of the DHT22 sensor with the ESP32 microcontroller enabled the effective acquisition of environmental data. Once collected, the data was transmitted to a cloud platform (Firebase), which was accessed through both a mobile application and a web interface. Users can instantly view real-time temperature and humidity readings on their smartphones, supporting efficient environmental monitoring. Figure 3 shows the appearance of the output.

The system provided a temperature of 28.40°C and a varying humidity of (71.80%) under these conditions. The DHT22 sensor provided approximate measurements with a temperature and humidity precision of ±0.5°C and ±2%, respectively. These precision levels are within the range required for drug manufacturing and ensuring that the conditions for storing drugs are maintained within the given limit. The results of the tests are summarized in Table 1.

Making sure that environmental conditions (temperature and humidity) do not exceed the required conditions; if they exceed the required conditions, an alarm is triggered. To avoid unusual conditions, the system is programmed in such a way that it will give a warning when the temperature and humidity increase to 30°C and 75%, respectively. After detecting these conditions, the alert mechanism was activated within 5 s.

The total system response time, including data sensing, processing, cloud communication, and app notification, was less than 5 s. This immediate reply ensures that necessary actions are taken immediately, minimizing the risk in drug manufacturing.

Overall, the objectives of the developed system are to access real-time data, provide quick alerts, and ensure accurate sensing. This provides a scalable and efficient solution for maintaining storage conditions in pharmaceutical manufacturing.

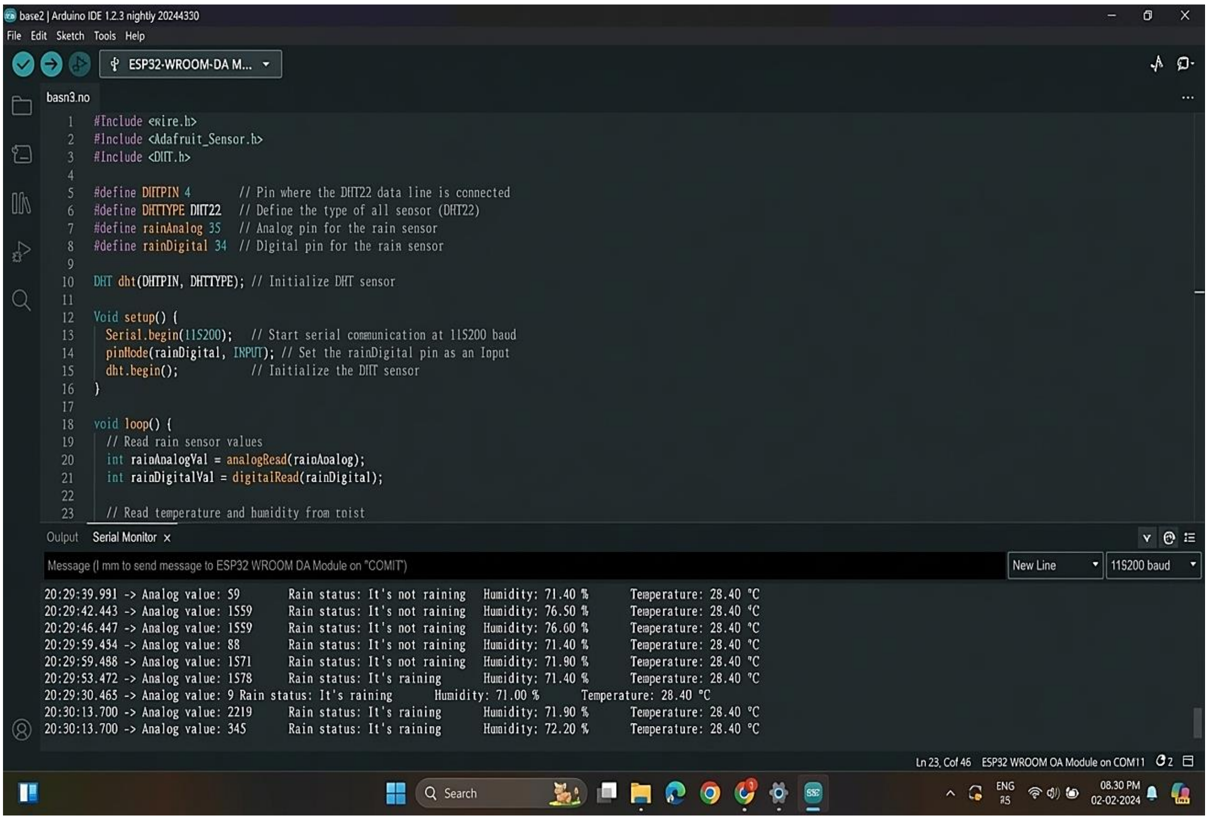

Figure 3. Output of the system.

Table 1. Actual versus expected environmental readings.

Test scenario	Expected temp. (°C)	Actual temp. (°C)	Expected humidity (%)	Actual humidity (%)
Normal room condition	28.0	28.4	70.0	71.8
Thresholds exceed the condition	>30.0	30.3	>75.0	76.5

CONCLUSION

Temperature and humidity are the most essential parameters that must be maintained in pharmaceuticals to ensure stability and safety. Hence, this system, that is, an IoT-based Real-time Monitoring System for Temperature and Humidity Control in Pharmaceutical, was designed to meet these requirements.

Affordable components, such as the DHT22 sensor (for monitoring temperature and humidity data), ESP32 microcontroller (for data processing), and cloud service, such as ThingSpeak (for alert management), are used, which makes it cost-effective.

The primary aim of this system is to enable continuous tracking, non-automation, and ensure that quick actions are taken when unusual and unexpected conditions occur.

When tested in a simulated pharmaceutical production environment, the system consistently monitored and controlled the temperature and humidity levels with high precision. It has impressive system availability, maintains accurate data, and provides real-time alerts when unexpected conditions occur.

The system gives real-time data with minimized human error.

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