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DESIGN AND PROTOTYPE DEVELOPMENT OF AN IOT-BASED TEMPERATURE AND HUMIDITY MONITORING SYSTEM WITH REAL-TIME DATA AND AUTOMATED ALERTS

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Abstrak
Penelitian ini menyajikan perancangan dan implementasi sistem pemantauan suhu dan kelembapan ruangan berbasis Internet of Things (IoT) secara waktu nyata. Sistem mengintegrasikan sensor DHT11 dengan mikrokontroler ESP32-C3-WROOM-2 untuk mengukur suhu dan kelembapan pada rentang 0–50 °C dan 20–90% kelembapan relatif dengan akurasi ±2 °C dan ±5% RH. Data pengukuran ditampilkan pada LCD 20×4 I2C dan dikirimkan melalui Wi-Fi ke Google Sheets untuk penyimpanan dan analisis berbasis cloud, serta dilengkapi notifikasi otomatis melalui WhatsApp ketika parameter lingkungan melebihi ambang batas yang ditentukan.
Hasil pengujian kalibrasi menggunakan alat standar HTC-2 menunjukkan rata-rata kesalahan pengukuran sebesar 1,594%, yang masih berada dalam batas toleransi sensor DHT11. Uji konsistensi pada lingkungan berpendingin dan tanpa pendingin menunjukkan sistem mampu mendeteksi variasi lingkungan secara akurat, dengan fluktuasi lebih tinggi pada ruang berpendingin akibat siklus HVAC. Sistem ini mengurangi kebutuhan intervensi manual, mendukung pemantauan berkelanjutan, dan menawarkan solusi pemantauan lingkungan yang andal, hemat biaya, serta aplikatif untuk sektor rumah tangga, komersial, dan industri.

Kata Kunci: *Internet of Things*, pemantauan lingkungan, ESP32, sensor DHT11, akuisisi data waktu nyata

Abstract
This study presents the design and implementation of an Internet of Things (IoT)-based system for real-time monitoring of room temperature and humidity. The system integrates a DHT11 sensor with an ESP32-C3-WROOM-2 microcontroller to measure environmental parameters within ranges of 0–50 °C and 20–90% relative humidity, achieving accuracies of ±2°C and ±5% RH, respectively. Measurement data are displayed on a 20×4 I2C LCD and transmitted wirelessly via Wi-Fi to Google Sheets for cloud-based storage and analysis. The system features an automatic notification mechanism that sends alerts through WhatsApp when environmental conditions exceed predefined thresholds. Calibration testing against the HTC-2 reference standard device demonstrated a total average measurement error of 1.594%, confirming compliance with the DHT11 sensors specified tolerance limits. Consistency tests conducted in both air-conditioned and non-air-conditioned environments revealed that the system effectively captures genuine environmental variations, with higher variability observed in mechanically controlled spaces due to HVAC operational cycles. The developed prototype successfully addresses limitations of conventional monitoring methods by eliminating manual intervention requirements, enabling continuous real-time surveillance, and facilitating rapid preventive actions. Results indicate that the system provides sufficient measurement accuracy and stability for practical applications in residential, commercial, and industrial environmental monitoring, while offering a cost-effective and accessible solution for IoT-based climate control systems.

Keywords*: *Internet of Things, environmental monitoring, ESP32, DHT11 sensor, real-time acquisition

1.0 INTRODUCTION

Precise regulation of indoor temperature and humidity is critical for occupant comfort, product quality, and the protection of sensitive equipment in residential, commercial, and industrial environments. Manual monitoring methods are often non-integrated, lack real-time data transmission, and do not provide the accuracy required for timely detection of environmental changes[1]. These limitations can result in increased energy consumption, damage to sensitive equipment, microbial proliferation due to excessive humidity, and reduced storage quality. The adoption of Internet of Things (IoT) technology addresses these challenges by enabling automated monitoring systems that deliver real-time environmental data to users, supporting prompt and informed decision-making[2].

The Internet of Things (IoT) has facilitated substantial advancements in the design and implementation of indoor temperature and humidity monitoring systems. IoT enables the integration of diverse sensor devices via the internet, supporting real-time data acquisition, transmission, and analysis without direct human involvement[3]. Monitoring systems that utilize IoT technology offer advantages such as enhanced measurement accuracy, remote data accessibility, and seamless integration with automation systems, including air conditioning and humidification units[4]. Additionally, IoT-based systems can issue early warnings when environmental conditions exceed set thresholds, allowing for prompt and effective corrective actions[5]. These features position IoT as a robust solution to the limitations of conventional monitoring methods in maintaining temperature and humidity stability, while also promoting energy efficiency, protecting equipment, and ensuring product storage quality.

Internet of Things (IoT) technology has brought significant changes to the design and use of room temperature and humidity monitoring systems. IoT enables room temperature and humidity monitoring to operate without human intervention, as various sensor devices and other systems are connected to each other via the internet, allowing for real-time data acquisition, transmission, and analysis[6][7]. The use of IoT in temperature monitoring offers several advantages, including increased monitoring accuracy, easy remote data access, and the ability to integrate with other automation systems, such as air conditioning and air humidity control[8]. IoT-based monitoring systems also feature an early warning system that alerts users when environmental conditions exceed specified normal limits, allowing for prompt and accurate corrective actions[9]. The advantages of IoT include its ability to overcome the limitations of conventional methods in monitoring temperature and humidity, while also supporting energy efficiency, equipment protection, and maintaining product storage quality[10].

Although IoT-based room temperature and humidity monitoring systems have been widely developed, most still have limitations in terms of functionality and effectiveness. Existing systems are mostly only capable of monitoring without automatic warning or data recording features, so human intervention is still needed for manual monitoring[11]. Additionally, cost factors and inflexible designs render them ineffective for use in various types of rooms. These limitations present an opportunity for the development of an integrated, efficient, and accessible monitoring system that can provide real-time data, automatically store information, and send notifications when environmental conditions exceed the specified limits[12]. Based on these issues, this study was conducted to design and build an IoT-based room temperature and humidity monitoring device that can quickly detect changes in environmental conditions, display data through an easily accessible interface, and provide automatic notifications to users, thereby supporting effective decision-making.

This research aims to design and implement an Internet of Things (IoT)-based system for monitoring room temperature and humidity, integrated with a digital interface and an automatic notification mechanism. The proposed system measures environmental conditions in real-time, displays data via an LCD screen or a web-based platform, and sends automatic alerts through a messaging application when temperature or humidity parameters exceed predefined thresholds. This approach enables users to monitor environmental conditions efficiently, eliminating the need for manual checks, while also facilitating rapid preventive actions to maintain stable room conditions. Furthermore, the findings of this study are intended to serve as a scientific reference for the development of effective, economical, and practical environmental monitoring technologies for domestic, commercial, and industrial applications.

2.0 RESEARCH METHOD

2.1. Tools and Materials

An engineering experimental approach was employed to design and implement an Internet of Things (IoT)-based temperature and humidity monitoring system. This methodology facilitated the integration of hardware design, software development, and comprehensive system performance testing.

The primary hardware includes a DHT11 sensor for measuring temperature and humidity within a range of 0–50 °C and 20–90% relative humidity (RH), with an accuracy of ±2 °C and ±5% RH, respectively. The ESP32-C3-WROOM-2 microcontroller serves as the system control unit, transmitting data wirelessly via Wi-Fi. A 20×4 I2C LCD provides a local display of measurement results. The system operates on a 3.7 V battery, and all components are enclosed in a PVC case to minimize environmental interference.

The software was developed using the Arduino Integrated Development Environment (IDE) to acquire sensor data, transmit it to the Google Sheets platform through Google Apps Script, and implement warning logic when temperature or humidity values exceed predefined thresholds. The system enables real-time monitoring of environmental conditions through seamless integration of hardware and cloud-based software.

2.2. Research Stages

The research stages are systematically organized to ensure a consistent and measurable framework for system development and evaluation, as briefly illustrated in Figure 1.

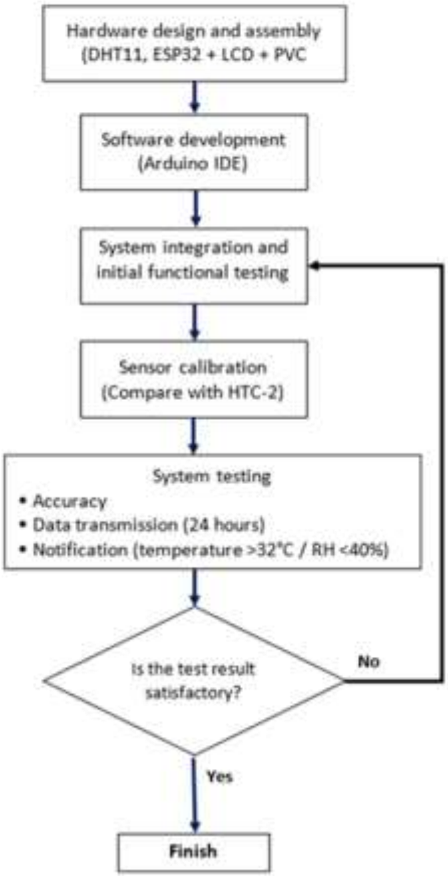

Figure 1: Flowchart of the IoT-Based Temperature and Humidity Monitoring System Development Process

The subsequent stage is system design and assembly, which includes connecting the DHT11 sensor to the ESP32 microcontroller and integrating the LCD module as a display interface. This phase also addresses the mechanical design, positioning components within a PVC enclosure to enhance safety and portability. Figure 2 illustrates a wiring diagram showing the connections between the temperature sensor, microcontroller, and LCD. The diagram details the data, power, and control signal lines that enable the system to accurately read, process, and display temperature data.

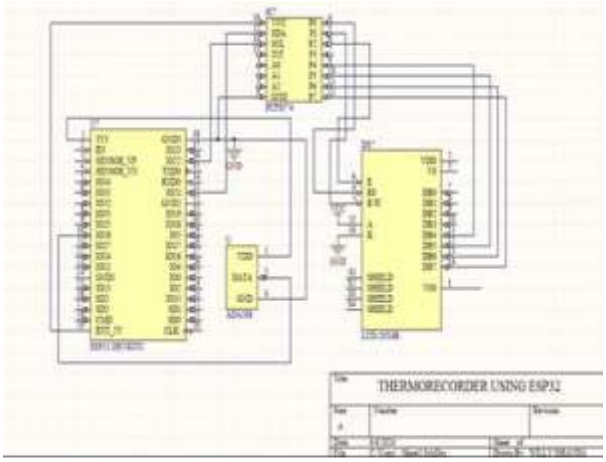

Figure 2: Wiring Diagram of ESP32-Based Temperature and Humidity Monitoring System

Software development follows, utilizing the Arduino IDE to manage data acquisition, cloud transmission via Wi-Fi, and the dispatch of automatic notifications when parameters exceed predefined thresholds. Upon verification, the code is uploaded and tested to confirm that all functions operate as designed.

System integration is achieved by combining hardware and software, followed by testing to verify operational stability, data communication, and LCD display functionality. Sensor calibration is conducted by comparing measurement results with a reference instrument (HTC-2) in a controlled environment. Ten data points are collected every 30 seconds to calculate relative error and assess accuracy.

The system testing stage includes evaluating accuracy, transmission reliability, and response time. Sensor consistency test is conducted under two environmental conditions (air-conditioned and non-air-conditioned) for 30 minutes, with a 10-second reading interval, and analyzed. Additionally, data transmission testing is performed for 24 hours to assess the success percentage of communication based on HTTP responses, while notification testing is carried out by simulating a temperature >32 °C or humidity <40 percent to measure the latency between detection and message reception.

2.3. Data Analysis

Measurement data are automatically collected by the microcontroller at ten-second intervals and stored in Google Sheets as a table containing time, temperature, and humidity values. Quantitative analysis is conducted using descriptive statistical methods to determine the mean, standard deviation, and distribution of the measurement results.

The measurement error rate is calculated using the following equation[13]:

$$E_T = \left|\frac{T_{DHT11} - T_{HTC-2}}{T_{DHT11}}\right| \times 100\% \quad (1)$$

$$E_H = \left|\frac{H_{DHT11} - H_{HTC-2}}{H_{DHT11}}\right| \times 100\% \quad (2)$$

In this equation 1 E_T represents the percentage error for temperature, and in equation 2 E_H represents the percentage error for humidity. Additional parameters analyzed include precision, response time, transmission reliability, and notification system latency, as well as accuracy.

3.0 RESULT AND DISCUSSION

3.1. Hardware Assembly and System Integration

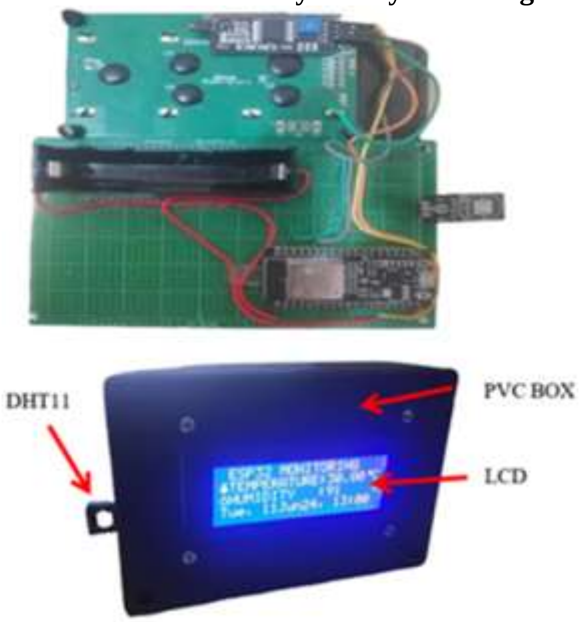

Figure 3: Electronic Circuit Assembly and Hardware Implementation of the ESP32-Based Temperature and Humidity Monitoring System.

Figure 3 presents the assembled ESP32-based temperature and humidity monitoring system. The configuration consists of three primary components: the ESP32 microcontroller, DHT11 sensor, and LCD module, all housed within a PVC enclosure for protection and portability. The ESP32 is programmed to acquire temperature and humidity data from the DHT11 sensor, process the measurements, and transmit the results wirelessly to a data logger or monitoring platform using a Wi-Fi connection. The LCD module serves as a real-time display, allowing for the immediate visualization of measured parameters.

The system is powered by a 3.7 V rechargeable battery, which supplies energy to all modules and supports both portability and energy efficiency. The integration and operation of all components, as depicted in Figure 3, demonstrate that the electronic circuit has been assembled correctly and is capable of real-time monitoring, aligning with the design objectives.

3.2. System Programming and Output Verification

The temperature and humidity monitoring system was developed using the Arduino IDE, with the ESP32 platform serving as the primary microcontroller. Experimental results confirmed that the ESP32 successfully executed all assigned functions, including acquiring data from the DHT11 sensor, displaying measurements on the LCD module, and transmitting data and notifications in real-time via Wi-Fi.

Figure 4: Serial monitor output showing real-time temperature and humidity data transmission process

Figure 4 displays the serial output of temperature and humidity readings generated by the ESP32, which demonstrates reliable sensor data acquisition and serial communication. The results indicate that the microcontroller consistently receives and processes signals from the sensor without errors.

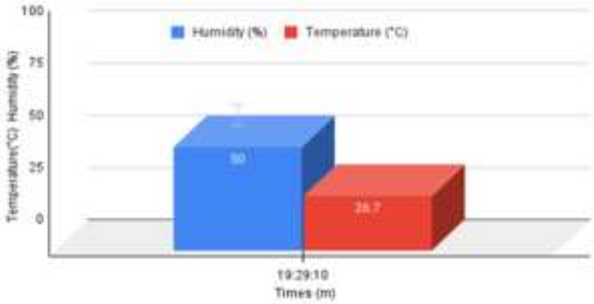

Figure 5: Real-Time Temperature and Humidity Monitoring Chart

Figure 5 shows the system's ability to monitor temperature and humidity in real-time through a graphical interface that displays temporal variations in environmental parameters. This visualization features two primary data streams: the red line represents temperature (°C) and the blue line indicates relative humidity (%), both plotted against time to highlight the system's capability for simultaneous multi-parameter monitoring. This graphical representation allows users to observe dynamic fluctuations in environmental conditions and understand the relationship between changes in temperature and humidity. This real-time visualization capability overcomes the limitations of conventional monitoring systems, which rely on human labor, noting that continuous manual monitoring is inefficient and costly[14]. The automated system developed in this study eliminates this dependence, improves data acquisition resolution, and enables early detection of environmental disturbances that are often missed by manual inspections, thereby transforming a reactive approach into a more effective proactive surveillance system.

The system also includes an automatic notification mechanism that activates when temperature or humidity exceeds a specified threshold. Figure 6 provides evidence of this function, showing that the system sends warning messages via a WhatsApp bot using the CallMeBot API and the URLEncode library. The message is received in real time on the user's device, confirming the effectiveness of the warning mechanism and remote data transmission.

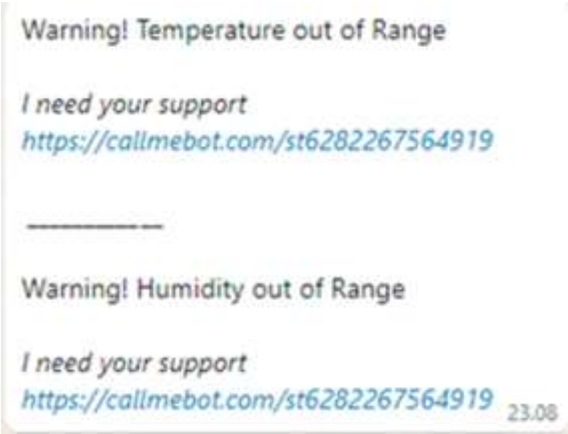

Figure 6: WhatsApp notification messages for out-of-range temperature and humidity alerts

3.3. Sensor Consistency Test

The sensor consistency test results reveal marked differences in the stability of DHT11 sensor readings across two environmental conditions, consistent with established sensor performance theory and environmental monitoring literature. In the absence of air conditioning, both temperature and humidity remained highly stable, resulting in a linear data pattern. The average temperature was 30.2 °C, with a standard deviation of 0.087. The relative humidity remained constant at 91%, with a standard deviation of 0.0. These results reinforce the principle that sensor measurement uncertainty is primarily influenced by environmental variability rather than intrinsic sensor drift, as noted in research on low-cost environmental sensors[15]. The consistently stable data further suggest that environmental disturbances during the 30-minute test period were negligible, aligning with the concept of thermal equilibrium in a closed space without active climate control.

Conversely, measurements in air-conditioned rooms exhibited substantially greater variability, reflecting the dynamic conditions of mechanically controlled environments. Temperature readings declined from a maximum of 28.5 °C to a minimum of 27.6 °C, with an average of 27.9 °C. Humidity fluctuated more significantly, ranging from 53.0% to 61%, with an average of 56.5% and a standard deviation of 2.24. These results align with the operational characteristics of HVAC systems, which generate temperature and humidity gradients over time through compressor cycles and periodic airflow[16]. The higher standard deviation observed in air-conditioned environments, compared to the non-air-conditioned room—defined in this study as an enclosed, unoccupied space with only passive ventilation—empirically demonstrates that sensor measurement consistency is influenced more by environmental dynamics than by sensor noise or drift.

These findings corroborate previous research on DHT series sensor performance under varying climatic conditions and underscore the necessity of distinguishing between sensor accuracy limitations and genuine environmental variability when interpreting IoT sensor data for building automation and environmental monitoring[17].

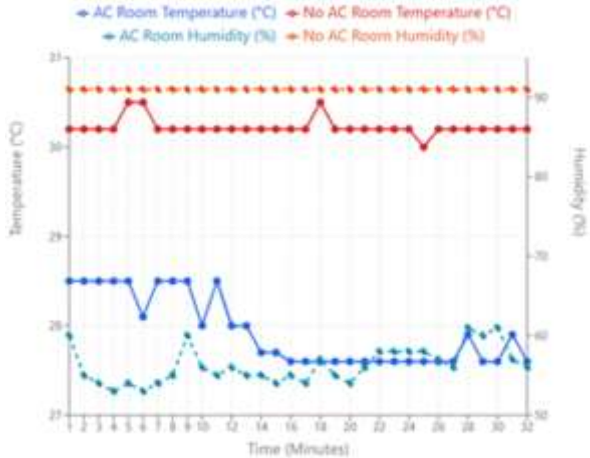

Figure 7: Temperature and humidity consistency test

Figure 7 shows the results of temperature and humidity consistency tests comparing environmental conditions between air-conditioned and non-air-conditioned rooms during a 32-minute monitoring period. The graph clearly shows different behavior patterns between the two environments: the non-air-conditioned room maintained very stable conditions throughout the test duration, with a consistent temperature of around 30°C (solid red line) and stable humidity in the range of 90% (dashed orange line). In contrast, the air-conditioned room showed significant variability, with the temperature (solid blue line) fluctuating between 27.5°C and 28.5°C during the first 14 minutes before stabilizing in the range of 27.5–28°C, while humidity (dashed cyan line) varied between 53% and 60% during the measurement period. The fluctuations in the air-conditioned room were caused by the cooling and dehumidification cycles of the air conditioning system, which actively regulates the indoor climate by removing heat and water vapor from the air. The contrasting differences between the dynamic, air-conditioned environment and the static, non-air-conditioned environment demonstrate that the sensor is capable of capturing actual environmental changes, rather than exhibiting measurement deviations or calibration errors, thereby confirming the reliability of the monitoring system in detecting real climate variations in both controlled and natural spaces.

3.4. Sensor Accuracy Testing

Temperature and humidity measurements obtained from the DHT11 sensor-based prototype device were compared with those from the HTC-2 Thermo standard device, which is commonly used in cleanroom laboratories as a reference for measurement. This comparison was conducted to evaluate the accuracy and reliability of the prototype device relative to a calibrated commercial instrument. The total measurement error was determined by first calculating the temperature error and humidity error at each measurement point using Equation (1) and Equation (2). The total error was then computed as the average of these two values. This total error value represents the overall accuracy of the measurement system based on the comparison between the prototype device and the manufacturer's standard device.

Table 1 presents a comparison of temperature and humidity measurements obtained from the DHT11 sensor prototype and the HTC-2 standard device, which served as the calibration reference. The analysis aimed to evaluate the accuracy of the sensor readings by directly comparing them with a certified reference device. This approach ensures measurement reliability and enables differentiation between genuine environmental variations and potential reading errors.

Table 1: Comparison of Measurement Results between the DHT11 Prototype and the HTC-2 Standard Device

NO	DHT11 Temp (°C)	HTC-2 Temp (°C)	Temp Error (%)	DHT11 Humid (%)	HTC-2 Humid (%)	Humid Error (%)
1	26.70	26.9	-0.7	52	53	-1.9
2	26.70	26.9	-0.7	52	53	-1.9
3	26.70	27.0	-1.1	54	52	3.7
4	26.70	27.1	-1.5	52	52	0
5	26.70	27.1	-1.5	52	52	0
6	26.70	27.2	-1.9	53	51	3.8
7	27.10	27.0	0.4	51	52	-2
8	27.60	27.1	1.8	51	52	-2
9	27.60	27.2	1.4	51	52	-2
10	28.00	27.4	2.1	49	52	-6.1
AVG	27.05	27.09	-0.2	51.7	52.1	-0.8

Across ten measurement points, the DHT11 sensor recorded temperatures ranging from 26.7°C to 28.0°C, while the HTC-2 device measured temperatures ranging from 26.9°C to 27.4°C. For humidity, the DHT11 reported values between 49% and 54%, while the HTC-2 indicated values between 51% and 53%. The calculated average temperaturee error was -0.2% and average humidity error was -0.8%, which remains within the DHT11 sensor's specified accuracy limits of ±2°C for temperature and ±5% relative humidity. These findings are consistent with previous studies demonstrating that the DHT11 achieves sufficient accuracy for IoT-based environmental monitoring when properly calibrated[18]. The error was determined using the standard method: the absolute difference between the measured value and the reference value, divided by the reference value. This method offers a realistic assessment of the multisensor system's accuracy[19]. Overall, the DHT11-based prototype demonstrates high accuracy and complies with industry tolerances, such as the ASHRAE standard, which permits deviations of up to 2–3% for HVAC systems. Prior research further confirms that the DHT11 sensor, when calibrated with reference devices like the HTC-2, delivers stable and accurate results for environmental monitoring, agricultural, and industrial applications at a cost-effective rate[20].

Figure 8 presents a comparison of temperature data collected from the DHT11 sensor-based prototype and the HTC-2 reference standard device. This graphical analysis aligns with established sensor validation protocols, as visualizing the correlation between the test instrument and the reference device provides clear evidence of measurement accuracy and reliability. Such comparison graphs facilitate the identification of systematic bias, random errors, and the degree of correlation between measurement systems in environmental monitoring contexts[21]. Both devices exhibit similar temperature trends, with the prototype recording values ranging from 26.7°C to 28.0°C, and the HTC-2 device recording values from 26.9°C to 27.4°C. This consistency supports previous findings that properly calibrated DHT series sensors demonstrate linear response and strong correlation (r > 0.90) with certified reference instruments within typical indoor temperature ranges[22].

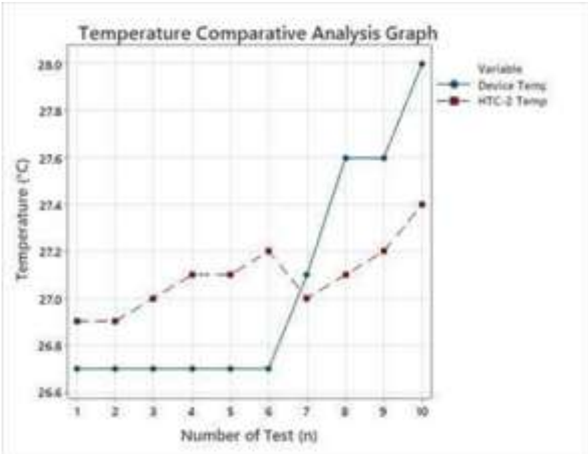

Figure 8: Temperature Comparative Analysis Graph Between the DHT11 Prototype and the HTC-2 Standard Device

The minimal difference between the two data sets demonstrates a satisfactory level of accuracy, as the measurement values remain within the ±2°C tolerance limit specified by the DHT11 manufacturer. This result aligns with previous research, which reported that the root mean square error (RMSE) of the DHT11 sensor was below 0.5°C compared to standard laboratory instruments[23]. Furthermore, several studies confirm that when sensor readings consistently fall within the manufacturer's specifications across various test points, the device is considered reliable for environmental monitoring applications[24].

The similarity in temperature trends between the two devices demonstrates that the prototype system consistently monitors temperature changes and closely approximates the measurements of the standard device. The small difference between the data lines indicates a satisfactory level of accuracy, as the variation remains within the DHT11 sensor's tolerance limit of ±2°C. Therefore, the results in Figure 8 confirm that the prototype device achieves sufficient accuracy in detecting temperature variations and produces data comparable to the calibrated HTC-2 device.

Figure 9 shows a graph comparing the humidity measurements between the DHT11 sensor prototype and the HTC-2 standard device based on ten tests. The humidity measurement results from the DHT11 (shown by the blue line) exhibit slight fluctuations between 49% and 54%, whereas the standard HTC-2 device (red line) displays more stable values in the range of 52% to 53%. This observed variability is consistent with the DHT11's documented specifications, which indicate a typical accuracy of ±5% RH in the 20-80% humidity range, and reflects the sensor's characteristic response to rapid environmental changes compared to precision reference instruments[25]. The small difference between the two devices demonstrates the DHT11 sensor's sensitivity to relatively rapid environmental fluctuations, while the HTC-2 shows more consistent performance typical of calibrated standard devices. Nevertheless, the data pattern indicates that the average humidity value of the DHT11 remains within a range comparable to that of the reference device, with deviations falling within the sensor's specified tolerance margins. These results suggest that this prototype has sufficient measurement accuracy and stability for environmental humidity monitoring applications, aligning with previous validation studies that confirmed DHT11 performance as adequate for indoor climate monitoring and IoT-based environmental sensing systems[26].

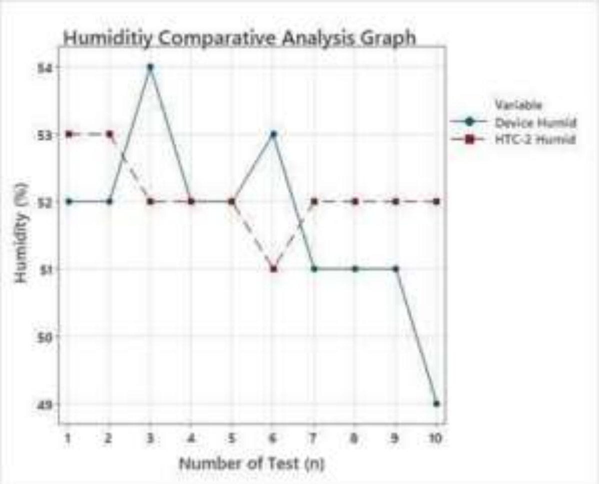

Figure 9: Comparative Humidity Analysis between the DHT11 Sensor Prototype and the HTC-2 Reference Device

4.0 CONCLUSION

The present study designed and implemented an Internet of Things (IoT)-based temperature and humidity monitoring system that measures environmental conditions in real-time, displays results on an LCD screen and a web-based platform, and sends automatic notifications via the WhatsApp application when temperature or humidity parameters exceed specified thresholds. Test results indicate that the system operates stably and accurately, with an average total error of 1.594% which remains within the tolerance limit of the DHT11 sensor. The system effectively detects environmental variations in both air-conditioned and non-air-conditioned rooms, achieving a level of accuracy comparable to that of the HTC-2 reference standard device. Nevertheless, certain limitations persist, including the use of sensors with limited resolution, the absence of an automatic control mechanism, and a restricted testing scope on a small scale. Future research should focus on employing sensors with higher accuracy, implementing automatic control systems, and integrating cloud-based data storage and mobile applications to enhance the scalability and reliability of the system, thereby facilitating comprehensive and sustainable environmental monitoring.

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