Design and Development of an IoT-Based Web Monitoring System for Temperature and Humidity Using Fuzzy Logic Inference

Gaguk Suprianto*[1], Muhammad Septama Prasetya[2]
[1]*Informatics, Faculty of Engineering and Design, Universitas Hayam Wuruk Perbanas, Surabaya, Indonesia*
[2]*Information System, Faculty of Computer Science, Universitas Pembangunan Nasional "Veteran" Jawa Timur, Surabaya, Indonesia*
E-mail : gaguk.suprianto@perbanas.ac.id[1], muhammad.septama.si@upnjatim.ac.id*
**Corresponding author*
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Abstract - Most Internet of Things (IoT)-based environmental monitoring systems primarily present raw sensor data, requiring users to interpret environmental conditions manually. This research focuses on developing a web-based IoT monitoring system for temperature and humidity, incorporating a Mamdani Fuzzy Logic Inference System (FIS) to interpret environmental conditions more effectively and support informed decision-making. The proposed system's novelty lies in integrating real-time IoT monitoring with fuzzy inference, enabling evaluation based on gradual transitions in temperature and humidity rather than rigid threshold boundaries. The system was implemented using an ESP32 microcontroller, a DHT22 sensor, a MySQL database, and a web-based dashboard. System evaluation included functional testing, end-to-end latency measurement, and continuous monitoring to assess system uptime and transmission performance. The functional testing confirmed that all major system modules operated successfully. The system achieved an average end-to-end latency of 230.02 ms across 50 consecutive transmissions and 100% uptime during an 8-hour continuous monitoring period, with 4,954 recorded transmissions and an average transmission interval of 5.81 s. The results show that the proposed system provides responsive, continuous environmental monitoring while integrating fuzzy-based environmental assessment to support more informed decision-making.

Keywords – Internet of Things, Environmental Monitoring, Web Monitoring, Mamdani Fuzzy Logic, Decision Support

1. INTRODUCTION

The availability of timely and accurate data is a critical factor in supporting various activities across multiple sectors, particularly in the operation of digital technology-based infrastructures [1]. Among various environmental parameters, temperature and humidity are essential indicators that require continuous monitoring because they significantly affect product quality, operational efficiency, and the reliability of equipment and facilities. Uncontrolled fluctuations in temperature and humidity can degrade product quality, disrupt operations, and reduce equipment performance. Therefore, real-time monitoring of these parameters is essential to support environmental condition control and enable faster and more accurate decision-making [2]. Accordingly, there is a need for a monitoring mechanism capable of providing real-time temperature and humidity data while supporting rapid and accurate analysis and decision-making recommendations.

Recent developments in Internet of Things (IoT) technology have facilitated the transition from conventional monitoring methods toward integrated and automated solutions with Internet-based communication capabilities.[3]. By utilizing sensors connected to microcontroller-based devices, environmental parameters such as temperature and humidity can be measured, collected, and transmitted in real time without requiring manual recording. The collected data are

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subsequently stored on cloud-based platforms, enabling users to access them through various digital devices from different locations [4]. This capability enables monitoring activities to be performed more efficiently, flexibly, and continuously. Previous studies have demonstrated that IoT implementation improves the efficiency of temperature and humidity data collection from rhizome drying processes while facilitating remote monitoring through web and mobile applications [5].

Nevertheless, most IoT-based monitoring systems primarily focus on presenting real-time sensor data without providing adequate analytical capabilities. The information generated is generally limited to displaying current environmental conditions in the form of tables and graphical visualizations. Through these visualizations, users can monitor sensor performance [6]. However, users are still required to manually interpret the data to determine appropriate actions. Consequently, the potential value of the collected sensor data has not been fully utilized.

To overcome these limitations, an analytical mechanism is required to automatically process sensor data so that the resulting information extends beyond numerical values and provides meaningful interpretations of environmental conditions together with actionable recommendations. In this study, environmental condition analysis is performed using a Mamdani Fuzzy Logic Inference System (FIS) based on a predefined rule base expressed as IF–THEN rules. In a fuzzy inference system, rules are expressed as IF–THEN statements that define how combinations of input variables are mapped to the corresponding output. Each rule consists of an IF condition that specifies the input criteria and a THEN statement that determines the corresponding output [7]. The analysis utilizes temperature and humidity ranges as input variables. Based on these rules, the system is capable of identifying environmental conditions, providing appropriate recommendations, and calculating an Environmental Score as an indicator of environmental quality. Therefore, the integration of IoT and Fuzzy Logic Inference not only enables real-time monitoring but also assists users in understanding environmental conditions and making faster and more informed decisions.

Research [8] developed an IoT-based environmental management system incorporating Mamdani fuzzy logic to optimize temperature and humidity conditions during the tempe fermentation process. The system integrated a DHT22 sensor, ESP32 microcontroller, and Blynk application to enable real-time monitoring and automated regulation of the fermentation environment.. The proposed system was designed to maintain the fermentation chamber within the optimal temperature range of 30–35°C and humidity range of 60–80%**,** thereby improving environmental stability and producing tempe with better texture and production consistency. However, the study primarily focused on automatic environmental control for fermentation optimization.

Previous research by [9] implemented a microcontroller-based fuzzy logic control system to regulate temperature and humidity in a coffee bean drying room. The proposed system employed an SHT11 temperature and humidity sensor, a microcontroller as the control unit, and a Mamdani fuzzy inference system with 10 fuzzy rules to control the heater and blower automatically. The fuzzy control process consisted of fuzzification, inference, rule-base evaluation, and defuzzification to maintain stable environmental conditions during the coffee drying process. The experimental findings showed that the developed system successfully kept the drying room temperature and humidity within the specified limits. The relatively small average deviations observed in temperature and fan control outputs further demonstrated the ability of the fuzzy logic controller to achieve stable and dependable environmental control.

A Mamdani fuzzy logic approach was implemented by [10] to develop an automated system for monitoring and maintaining room temperature within the desired conditions. The system employed an ESP32 microcontroller and a DHT22 sensor to monitor environmental conditions in real time, while a fan and heating lamp were used as actuators. Mamdani fuzzy logic was implemented to handle temperature uncertainty and generate gradual control decisions based on linguistic temperature categories, such as cold, warm, and hot. The experimental results from 15 temperature variations ranging from 21.5°C to 30.5°C demonstrated that the system was able

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to adjust the fan speed and heating lamp output responsively according to changes in room temperature. Unlike conventional ON/OFF control, the proposed fuzzy logic approach provided smoother actuator transitions through PWM and voltage adjustments. The study also integrated a web-based dashboard for real-time monitoring. However, the research was limited to temperature-based control and did not incorporate humidity as a control variable, while testing was conducted in only one indoor environment. These limitations indicate an opportunity for further research by integrating multiple environmental sensors and developing a more comprehensive intelligent control system for adaptive environmental monitoring and control.

Based on these three previous studies, it can be concluded that IoT-based environmental monitoring systems integrated with fuzzy logic have been successfully applied to evaluate environmental conditions and support automatic decision-making. The previous studies demonstrated that fuzzy inference methods are effective in processing environmental parameters, such as temperature, humidity, and air quality, to generate environmental classifications and control actions. However, the existing studies mainly focused on environmental control, air quality assessment, or process-specific monitoring applications. In addition, they generally did not integrate temperature and humidity monitoring with cloud-based data storage, historical data visualization, real-time web dashboards, and environmental scoring for decision-support purposes. Therefore, the present study proposes an IoT-based web monitoring system that combines real-time temperature and humidity monitoring with a Mamdani Fuzzy Logic Inference System to provide comprehensive environmental assessment, environmental scores, and actionable recommendations for indoor office environmental monitoring.

Although several previous studies have applied fuzzy logic for environmental monitoring, many practical temperature and humidity monitoring systems still rely on crisp threshold-based rules, which assume strict boundaries between environmental conditions. In reality, environmental parameters change gradually, making threshold-based classification less flexible and realistic.

To address this limitation, the proposed study employs a Mamdani Fuzzy Logic Inference System (FIS) to assess indoor environmental conditions using temperature and humidity as the primary input parameters. The system combines a DHT22 sensor and an ESP32 microcontroller with Firebase Realtime Database and a web-based dashboard to enable real-time environmental monitoring. Beyond displaying sensor data, the proposed system also incorporates environmental scoring, condition classification, historical data recording, and actionable recommendations to assist decision-making in indoor office environments.

2. RESEARCH METHOD

A Research and Development (R&D) methodology was applied in this study to systematically design, develop, and evaluate the proposed system [11]. A Research and Development (R&D) methodology was adopted in this study, as it provides a systematic framework for designing, developing, implementing, and evaluating a technological system through a structured and iterative process. The R&D methodology facilitates the integration of hardware, software, database, and intelligent analysis components throughout the system development process.

This study applied an R&D methodology in the development of an IoT-enabled temperature and humidity monitoring system, enhanced with a Mamdani Fuzzy Logic Inference System (FIS) to assess indoor environmental conditions. Real-time sensor data acquisition is performed by the proposed system through an ESP32 microcontroller and a DHT22 sensor, which stores the collected data in a MySQL database and analyzes environmental conditions through fuzzy logic inference to generate environmental scores, risk classifications, and decision-support recommendations. The research procedure consisted of seven stages: (1) problem identification, (2) literature review, (3) system design, (4) system implementation, (5) system testing and

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performance evaluation, (6) data analysis and interpretation, and (7) conclusion and recommendation. The testing and evaluation stage included functional testing, fuzzy logic validation, end-to-end latency measurement, and an eight-hour continuous uptime test to evaluate the reliability and operational stability of the proposed system. Figure 1 provides an overview of the methodological framework followed throughout this study.

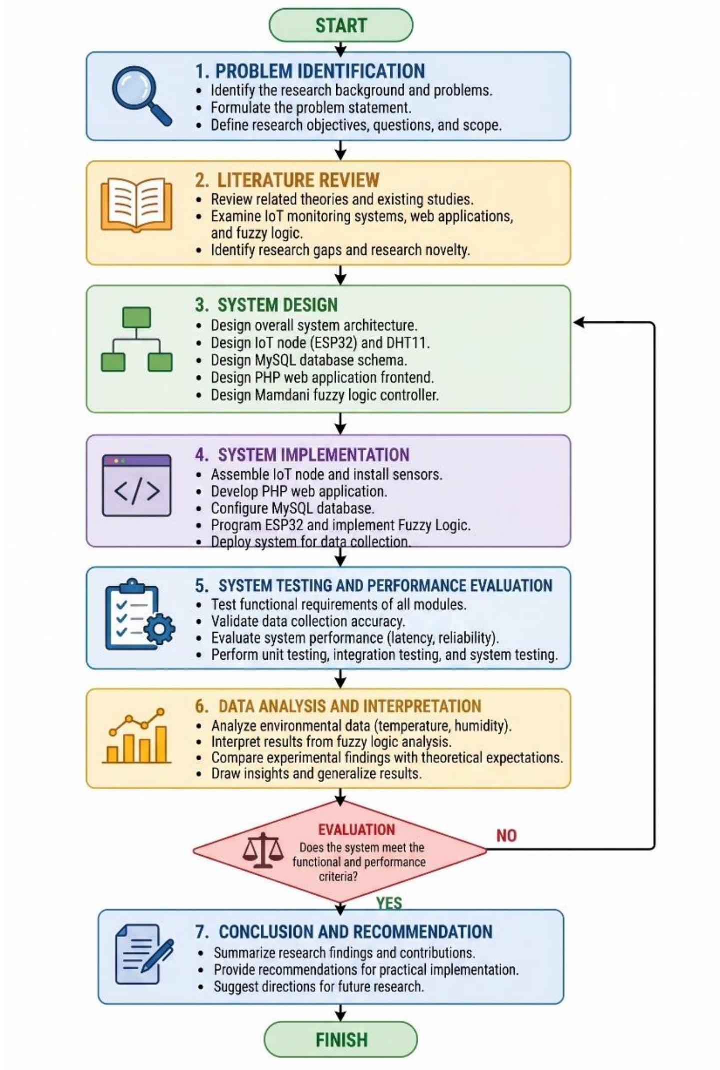

Figure 1. Research Methodology Flow

2.1. Problem Identification

The research began by defining the underlying problem and establishing the objectives of the proposed study. The research took place in an office environment, where controlled temperature and humidity levels are essential for ensuring occupant comfort, supporting productivity, and maintaining the operational reliability of office equipment. Continuous monitoring of environmental conditions is therefore required to support a healthy and stable indoor working environment.

Conventional threshold-based monitoring systems often generate rigid decisions because they rely on fixed temperature and humidity limits and cannot effectively handle gradual transitions or uncertainties in environmental conditions. To address this limitation, this research aimed to develop an IoT-based environmental monitoring system integrated with a Mamdani

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Fuzzy Logic Inference System (FIS). The proposed system was designed to perform real-time environmental monitoring, generate environmental assessment scores, classify environmental conditions, and provide decision support based on temperature and humidity measurements.

The temperature and humidity assessment ranges were designed to represent typical indoor office environmental conditions and were based on recommended indoor thermal comfort conditions reported in the ASHRAE thermal comfort guidelines [12]. Similar environmental parameters have also been employed in previous IoT-based indoor environmental monitoring studies to evaluate indoor environmental quality and support decision-making processes. This environmental context provides the basis for the fuzzy membership functions and environmental assessment model used in the proposed system

2.2. Literature Review

This stage involved reviewing relevant literature related to Internet of Things (IoT)-based environmental monitoring systems, web-based monitoring applications, database integration, and Mamdani Fuzzy Logic Inference Systems (FIS). The literature review was conducted to establish the theoretical foundation of the proposed system and to identify the limitations of existing threshold-based monitoring approaches. Previous studies were analyzed to evaluate sensor-based data acquisition methods, real-time web monitoring architectures, environmental assessment techniques, and intelligent decision-support mechanisms.

The findings from the literature review were used to establish the system specifications and implementation needs, including the selection of ESP32 and DHT22 for real-time data acquisition, MySQL for data storage, PHP for web-based monitoring, and the Mamdani Fuzzy Logic Inference System for assessing environmental conditions and generating recommendations. In addition, the literature review helped determine the appropriate temperature and humidity parameters, fuzzy membership functions, and rule base used in the system design and implementation stages [13].

2.3. System Design

The system architecture was designed by integrating IoT hardware, database infrastructure, web application modules, and fuzzy logic processing. The hardware subsystem consisted of an ESP32 microcontroller and a DHT22 temperature and humidity sensor. The software subsystem included a PHP-based web application and a MySQL database for real-time data storage and retrieval. The fuzzy logic subsystem was designed by defining the input variables, membership functions, fuzzy rule base, inference mechanism, and centroid defuzzification method. The system design also included data communication, dashboard visualization, historical data management, and environmental score generation.

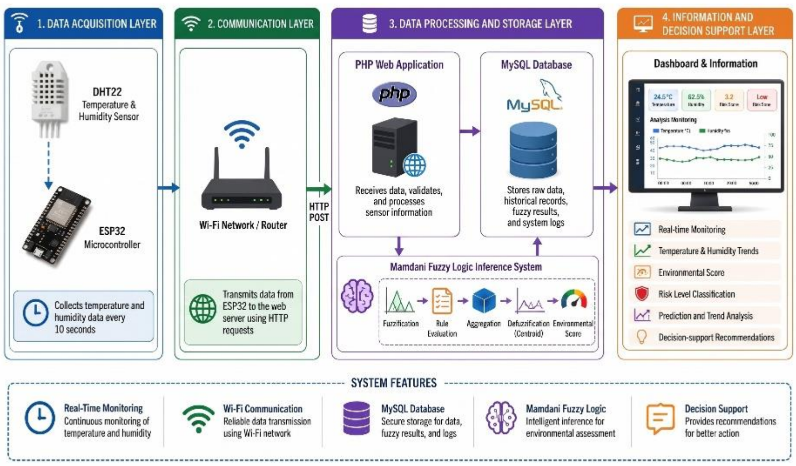

Figure 2. System Architecture

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2.4. System Implementation

During the implementation stage, the proposed system was developed based on the designed architecture. The DHT22 sensor provided continuous temperature and humidity measurements, which were collected by the ESP32 and subsequently sent to the web server over a Wi-Fi network. The collected data were stored in a MySQL database and processed by the PHP-based web application for real-time monitoring and historical data visualization. The Mamdani Fuzzy Logic Inference System was implemented to analyze environmental conditions and generate environmental scores, risk levels, and operational recommendations.

2.5. System Testing and Performance Evaluation

System evaluation involved two main aspects: functional verification and performance assessment. The functional aspect was examined to confirm that each module of the developed system performed according to its intended purpose [14], including sensor acquisition, data transmission, database storage, web visualization, and fuzzy inference processing. The fuzzy logic implementation was validated by comparing the system output with manual fuzzy calculations. Furthermore, the communication performance was evaluated through end-to-end latency testing, which measured the response time of the monitoring system from sensor data transmission to server processing and dashboard visualization. An eight-hour continuous uptime test was also performed under normal indoor operating conditions to evaluate the reliability and operational stability of the monitoring system during continuous operation.

2.6. Data Analysis and Interpretation

The collected monitoring data were analyzed to evaluate the performance of the proposed system. The analysis included temperature and humidity trends, environmental score distribution, fuzzy inference results, risk level classification, and prediction performance. The results of latency and uptime testing were also analyzed to assess the efficiency and reliability of the IoT communication system. The findings were interpreted by comparing the system performance with the research objectives and the operational requirements of intelligent environmental monitoring systems.

2.7. Conclusion and Recommendation

The final stage involved drawing conclusions based on the implementation results and performance evaluation. The effectiveness of integrating IoT technology with the Mamdani Fuzzy Logic Inference System was assessed in terms of monitoring capability, environmental assessment accuracy, communication performance, and decision-support functionality. Finally, recommendations were proposed for future research, including the integration of machine learning-based prediction models, cloud-based data synchronization, mobile application development, and the expansion of the system to support additional environmental parameters and industrial-scale monitoring applications.

3. RESULTS AND DISCUSSION

3.1. System Implementation Result

Implementation of the IoT-based environmental monitoring system involved the integration of an ESP32 microcontroller, DHT22 temperature and humidity sensor, PHP-based web application, MySQL database, and Mamdani Fuzzy Logic Inference System. The developed dashboard provides real-time visualization of temperature, humidity, environmental scores, risk classifications, and historical monitoring data. Figure 3 presents the web dashboard, which combines fuzzy logic analysis with recommendation features in a unified interface. Through this platform, users can monitor environmental conditions while obtaining information to support decision-making.

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Figure 3. Sensor Data and Device Status Interface

3.2. Real-time Monitoring Result

Figure 4 presents the real-time temperature and humidity monitoring results obtained from the proposed IoT-based environmental monitoring system. The graph illustrates the temporal variation of both environmental parameters collected by the DHT22 sensor and transmitted continuously through the ESP32 microcontroller.

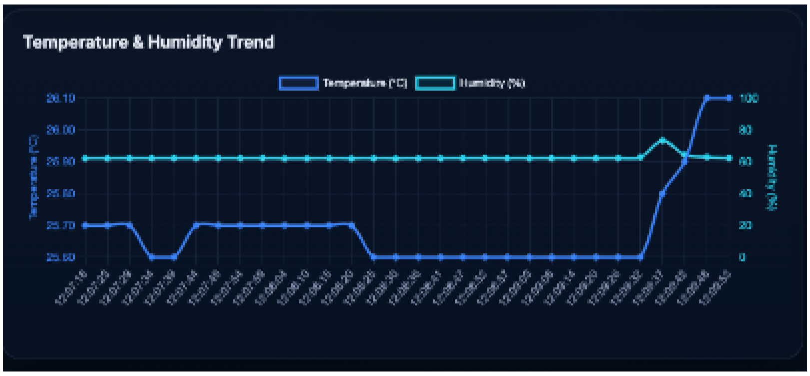

Figure 4. Real-time temperature and humidity monitoring results.

During the observation period, the temperature values ranged from approximately 25.4°C to 26.0°C, while the humidity measurements varied between 62% and 70%.The recorded measurements show relatively stable patterns for both environmental parameters throughout the observation. However, an upward trend became evident toward the end of the monitoring session. This simultaneous visualization of temperature and humidity provides a comprehensive representation of environmental conditions over time.

The temperature exhibited gradual variations, whereas humidity showed a slightly larger fluctuation, reflecting the sensitivity of relative humidity to short-term environmental changes. The increase observed at the end of the monitoring period demonstrates the system's capability to capture dynamic environmental changes and update the monitoring dashboard in real time.

These results confirm that the proposed IoT monitoring system successfully acquired, transmitted, stored, and visualized environmental data continuously throughout the observation period. The synchronized monitoring of temperature and humidity provides reliable environmental information for subsequent environmental assessment and decision-support analysis.

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3.3. Mamdani Fuzzy Logic Inference Result

Environmental conditions are assessed using a Mamdani Fuzzy Logic Inference System (FIS), with temperature and humidity measurements serving as the input variables. The inference mechanism comprises four sequential stages, namely fuzzification, rule evaluation, aggregation, and defuzzification [15]. During the fuzzification stage, the measured temperature and humidity values are transformed into fuzzy membership values using predefined linguistic variables. Temperature is represented by the fuzzy sets Low, Optimal, and High, while humidity is represented by Dry, Normal, and Humid.

Figure 5 illustrates the membership functions and the corresponding environmental assessment result generated by the proposed system. The temperature membership functions were designed with overlapping regions to represent gradual transitions between environmental conditions. Similarly, the humidity membership functions employ overlapping fuzzy sets that allow a single measurement to belong partially to multiple linguistic categories.

In the example shown in Figure 5, a temperature of 26.0°C and a humidity of 62.1% activate the Optimal temperature membership function and the Normal humidity membership function. The activated fuzzy rules are aggregated and converted into a numerical environmental score using the centroid defuzzification method. The resulting environmental score of 95.0 is classified as Good, indicating that the measured environmental conditions fall within the desired operating range.

Figure 5. Temperature and humidity membership functions and the corresponding environmental assessment result

3.4. Functional Testing Result

The functionality of each IoT-based environmental monitoring component was verified against its specified operational requirements. The evaluation focused on data acquisition, communication, database integration, web visualization, fuzzy inference processing, and recommendation generation. Each function was tested repeatedly under normal operating conditions to ensure that the system performed according to the design specifications. Table 1 summarizes the outcomes obtained from the functional verification process.

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Table 1. Functional Testing Result

Functional Module	Testing Procedure	Result
Temperature Acquisition	Read temperature from DHT22 sensor	Successful
Humidity Acquisition	Read humidity from DHT22 sensor	Successful
Data Transmission	Transmit sensor data from ESP32 to the web server via HTTP	Successful
Database Storage	Store received data in the MySQL database	Successful
Real-Time Dashboard Update	Display temperature and humidity data on the web dashboard	Successful
Environmental Assessment	Generate environmental score and condition classification	Successful
Recommendation Generation	Generate operational recommendations based on assessment result	Successful

The testing results demonstrate that all functional modules operated successfully without execution errors. The ESP32 microcontroller consistently acquired temperature and humidity measurements from the DHT22 sensor and transmitted the data to the PHP web application through HTTP communication. The web application successfully processed the incoming data and stored the measurements in the MySQL database for subsequent analysis and visualization.

The dashboard interface displayed real-time environmental data, historical trends, environmental scores, and risk classifications without synchronization issues. The Mamdani Fuzzy Logic Inference System correctly processed the temperature and humidity inputs and produced environmental scores consistent with the predefined membership functions and rule base. In addition, the recommendation module generated appropriate operational recommendations based on the fuzzy inference results.

Overall, the functional testing confirms that the proposed system successfully integrates IoT data acquisition, web-based monitoring, database management, and fuzzy logic-based environmental assessment into a unified monitoring platform. The successful operation of all functional modules provides the foundation for the communication performance evaluation presented in the following section.

3.5. Communication Performance Evaluation

The communication performance was assessed by analyzing the end-to-end latency and uptime of the proposed IoT-based environmental monitoring system under continuous operating conditions. The evaluation focused on measuring communication responsiveness and verifying the system's reliability while operating under real-time monitoring conditions.

The end-to-end latency was defined as the total time required for temperature and humidity data to be acquired by the DHT22 sensor, processed by the ESP32 microcontroller, transmitted through the Wi-Fi network, stored in the MySQL database, and displayed on the web dashboard. The latency was measured using the HTTP round-trip time, which represents the elapsed time between the initiation of the HTTP POST request on the ESP32 and the reception of the server response after data processing and database storage. The measurement was repeated for 50 consecutive data transmissions under normal operating conditions.

The average end-to-end latency was calculated using:

$$\bar{L} = \frac{1}{n}\sum_{i=1}^{n} L_i \quad (1)$$

Where:

$\bar{L} = Average\ end\ to\ end\ letency\ (ms)$

$L_i = Latency\ of\ the\ i-th\ transmission$

$n = Total\ number\ of\ measurements$

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To evaluate the variability of the communication delay, the sample standard deviation was calculated as

$$s = \sqrt{\frac{\sum_{i=1}^{n}(L_i - \bar{L})^2}{n-1}} \quad (2)$$

where:
$s = Sample\ standar\ deviation\ (ms)$
$\bar{L} = Average\ latency$
$L_i = Latency\ of\ the\ i-th\ transmission$
$n = Total\ number\ of\ measurements$

The latency measurement results are summarized in Table 2.

Table 2. The Latency Measurements

METRIC	VALUE
NUMBER OF TRANSMISSIONS	50
MINIMUM LATENCY	5 MS
MAXIMUM LATENCY	725 MS
AVERAGE LATENCY	230.02 MS
STANDARD DEVIATION	192.19 MS

The proposed IoT monitoring system achieved an average end-to-end latency of 230.02 ms, with a minimum latency of 5 ms and a maximum latency of 725 ms across 50 consecutive data transmissions. The average latency of less than 250 ms indicates that the system is capable of providing near real-time environmental monitoring and dashboard updates. The measured standard deviation of 192.19 ms indicates that communication delay varied across repeated transmissions, primarily due to fluctuations in wireless network conditions and server processing time during HTTP communication. Despite the observed variability, the average communication delay remained sufficiently low for continuous indoor environmental monitoring applications.

To evaluate the operational reliability of the proposed IoT-based environmental monitoring system, a continuous monitoring experiment was conducted for approximately eight hours under normal indoor operating conditions. During the monitoring session, the ESP32 processed the measurements generated by the DHT22 and communicated the collected data over a wireless network for subsequent storage and display through the web dashboard. System uptime was evaluated based on the proportion of time during which the monitoring system remained operational throughout the observation period.

$$Uptime\ (\%) = \frac{T_{operational}}{T_{observation}} x100\% \quad (3)$$

where:
$T_{operational} = total\ operational\ time\ (s)$
$T_{observation} = total\ observation\ time\ (s)$

Based on the monitoring records, the total observation time was 28,798 s. The calculated system uptime was 100%. In addition, 4,954 data transmissions were recorded during the observation period, with an average transmission interval of 5.81 s.

$$Uptime\ (\%) = \frac{28{,}798}{28{,}798} x100\% \quad (4)$$

The average transmission interval was calculated using:

$$T_{avg} = \frac{T_{total}}{N-1} \quad (5)$$

where
$T_{avg} = average\ transmission\ interval\ (s)$
$T_{total} = total\ monitoring\ time\ (s)$
$N = total\ number\ of\ recorded\ transmissions$

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For 4,954 recorded transmissions over 28,798 s:

$$T_{avg} = \frac{28{,}798}{4{,}954-1} = 5{,}81\ s \quad (6)$$

The results of the continuous monitoring and system uptime evaluation are summarized in Table 3.

Table 3. Continuous Monitoring and System Uptime Evaluation Results

PARAMETER	VALUE
MONITORING DURATION	8 HOURS
TOTAL MONITORING TIME	28,798 S
OPERATIONAL TIME	28,798 S
RECORDED TRANSMISSIONS	4,954
AVERAGE TRANSMISSION INTERVAL	5.81 S
OBSERVED DOWNTIME	0 S
SYSTEM UPTIME	100 %

Based on the results, the proposed IoT-based environmental monitoring system operated continuously throughout the eight-hour observation period without any observed interruption, resulting in an uptime of 100%. The system also maintained continuous data transmission with an average transmission interval of 5.81 s. These results demonstrate that the system was operationally stable during the tested indoor monitoring period. However, longer-duration testing is still required to further validate the long-term reliability and stability of the proposed system.

4. CONCLUSION

The proposed IoT-based environmental monitoring system successfully integrated ESP32, DHT22, web-based monitoring, and a Mamdani Fuzzy Logic Inference System. Functional testing confirmed that all major system modules operated successfully. The system achieved an average end-to-end latency of 230.02 ms and an observed uptime of 100% during eight hours of continuous monitoring, with 4,954 recorded transmissions at an average interval of 5.81 s. These results demonstrate that the proposed system provides responsive and operationally stable real-time environmental monitoring with fuzzy logic-based environmental assessment. However, longer-duration testing is required to further validate system reliability and stability under extended operating conditions.

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