

SMARTSENSE STM32 DRIVEN DUAL MODE IOT ENVIRONMENTAL MONITORING SYSTEM WITH REAL TIME MESSAGE DISPLAY

Padmapriya K

*Department of.Electronics and
Communication Engineering*

*AAA College of Engineering and
Technology*

Amathur,India

Kaleeswaran K

*Department of.Electronics and
Communication Engineering*

*AAA College of Engineering and
Technology*

Amathur,India

Gayathri M

*Department of.Electronics and
Communication Engineering*

*AAA College of Engineering and
Technology*

Amathur,India

Sweety A

*Department of.Electronics and
Communication Engineering*

*AAA College of Engineering and
Technology*

Amathur,India

Kalaivani S

*Department of.Electronics and
Communication Engineering*

*AAA College of Engineering and
Technology*

Amathur,India

Ramya M

*Department of.Electronics and
Communication Engineering*

*AAA College of Engineering and
Technology*

Amathur,India

Abstract-The design and experimental validation of a compact environmental monitoring system, which has been developed and tested, are discussed in this paper. The system is suitable for residential and industrial applications with minimal reliance on the external communication infrastructure. Monitoring of the environment is important for safety, comfort, and energy management, but the majority of existing IoT solutions suffer from problems such as one-way communication, inaccurate time stamping, dependence on internet connectivity and absence of interactive alerts. To solve these problems, a dual-mode system built around an STM32 microcontroller has been developed that incorporates a temperature and humidity sensor, real-time clock, organic light-emitting diode display, wireless communication, and an audible buzzer alert. This Built-in System continuously collects climate data, shows the time-stamped data on the spot, and allows two-way user communication with instant alert activation, thus guaranteeing a consistent offline operation. Testing results yield temperature readings within the range of 29.4 to 30.2 degrees Celsius and relative humidity of 60 to 63 percent, with an alert response time of under 200 milliseconds. The innovative system is a low-cost, reliable, and interactive solution for environmental monitoring with a promising future in multi-sensor integration and cloud-based data services expansion, among others.

Keywords-*Internet of Things;STM32 Microcontroller; Temperature and Humidity Sensor; Real-Time Clock; Organic Light-Emitting Diode Display; Buzzer Alert*

I. INTRODUCTION

Environmental monitoring has become increasingly important for maintaining safety, comfort, and operational efficiency in residential, industrial, and agricultural environments. The need for the optimal environmental conditions has been grown due to its direct

impact on human health [2], equipment performance [4], product quality [6], and energy consumption efficiency [8]. The correct environmental conditions in homes lead to better comfort and decreased health risks which arise from

low air quality and high temperature exposure. Industrial and agricultural areas require monitoring systems to verify equipment reliability and achieve maximum production efficiency while increasing crop yield [5].

The integration of Internet of Things (IoT) technologies has transformed environmental monitoring systems into intelligent, interconnected platforms. IoT enables automatic data acquisition [1] and simultaneous data processing [3] which allows users to see data results instantly [16] enabling them to take emergency actions while making educated choices. Automated systems decrease human errors because they require less human involvement while they deliver operational knowledge during times of fast environmental changes. The factory uses automated alerts to warn about temperature or humidity increases which helps protect equipment and ensure employee safety[19].

Temperature and humidity stand as vital environmental factors. The comfort [10] industrial productivity [12] and machinery durability [14] all suffer from minor changes in these two factors. Continuous and accurate measurement is necessary to maintain safe conditions [20], prevent hazardous situations [5], and improve energy management [9]. The modern monitoring systems execute predictive analysis [19] adaptive control [7] and system integration with smart building and agricultural management systems [15] to enable environmental change response by the system.

The IoT-based monitoring systems still need to overcome multiple challenges because of technological

advancements. The one-way communication system limits user interaction [18], which results in slow response times to environmental changes [11]. The lack of precise timestamps decreases historic data value [3] and predictive control effectiveness [1]. The majority of systems require uninterrupted internet access, which creates reliability problems in areas without internet connection [12]. The platforms lack local visualization [14] and alert systems [10], which create a situation where users must depend on cloud dashboards and mobile notifications. Critical intervention processes will experience delays during situations that require immediate response [6].

The existing problems show that there is a requirement for an environmental monitoring system which can deliver better accuracy and user engagement. The system needs to deliver real-time monitoring together with precise time tracking and site-based observation and immediate emergency notifications while reducing its need for outside network connections [16]. The system enables organizations to manage their daily activities while studying their complete historical records which helps them make predictions and adjust their management plans [4].

Modern environmental monitoring now assesses multiple environmental factors which exceed temperature and humidity assessment. Air quality, gas concentrations, and light intensity are increasingly monitored alongside traditional variables [5], [7], [19]. Cities and industrial areas need complete monitoring because various elements impact their operational productivity and employee protection and machine efficiency [1]. The combination of real-time monitoring and smart data analysis and user-friendly design creates a complete solution which addresses present-day environmental problems [16].

Energy efficiency gains from environmental monitoring because it helps organizations track their energy usage. The continuous temperature and humidity monitoring system in buildings enables HVAC systems to achieve better energy efficiency and cost savings through smart operation [9]. Industrial facilities and agricultural fields need perfect environmental conditions to protect machinery from breaking down and to save money while boosting production [10], [14].

The growing need for advanced intelligent monitoring systems rises because modern environments have become too complex and traditional monitoring systems face operational limits. The system requires real-time measurement capabilities together with accurate time stamping and interactive communication and local visualization and alert systems to support decision-making at the appropriate time with complete information. The development of the STM32-based dual-mode IoT environmental monitoring system aims to address the needs of residential and industrial and agricultural applications by providing a scalable and efficient and practical monitoring solution [4] [6] [8].

II. RELATED WORK

The research over the last few years has mainly focused on the development of IoT-based environmental monitoring systems that will automate and make the process of monitoring and managing environmental parameters in real-time. The first implementations were mainly based on basic sensing and remote monitoring through the use of microcontrollers like Arduino,

NodeMCU, and STM32. For instance, Verma et al. [20] made the first IoT-based environmental monitoring system that had sensors and wireless communication and it was a model for tracking the environment remotely. Likewise, the architectural framework introduced by Singh et al. [18] that was cloud-based enabled the nature data to be seen in real-time thus setting the stage for future IoT monitoring solutions. However, these primary attempts to the marketing of new products or services lacked features like interactive alert systems and precise time stamping that are very important for the monitoring to be accurate and the data to be thoroughly analyzed.

In the most recent research, STM32 microcontrollers have been applied to upgrade system performance and facilitate real-time monitoring. Dhrubo et al. [1] introduced a Bluetooth-based low latency IoT framework for local data access of temperature and humidity with an STM32. Chourasiya et al. [4] and Mehta et al. [7] created an STM32-based environmental monitoring station that sent data to a cloud dashboard for remote visualization. While these systems are more accurate and reliable, they do not have dual-mode communication or real-time alert responding features, resulting in limited interactivity.

Moreover, efforts have been made in the direction of multi-sensor configurations or edge-computing architectures to make the systems less power consuming and thus deployable for longer periods. Wiese et al. [3] suggested a multi-modal IoT node with very low power consumption optimized.

III. PROPOSED METHODOLOGY

The primary objective of this work is to develop a reliable environmental monitoring system which can measure ambient temperature and humidity while displaying real-time data through wireless communication and alerting capabilities. Such systems are essential in applications where continuous supervision of environmental conditions is required to ensure safety, comfort, and operational efficiency [1]. The proposed system uses the STM32 microcontroller as its central control unit to manage all sensing functions, processing tasks, communication needs, and alert systems.

The STM32 microcontroller offers efficient processing power with minimal power usage and comprehensive peripheral compatibility which makes it ideal for embedded sensing tasks [2]. The system controls data acquisition from sensors while managing communication protocols and displaying information and alert systems to enable seamless operation between all connected modules.

The DHT11 digital temperature and humidity sensor provides environmental data through its measurement capabilities. The sensor delivers calibrated digital signals which enable direct connection to the microcontroller without requiring analog-to-digital conversion [3]. The system conducts periodic data collection at established time intervals through digital input connections which receive sensor output data. This method enables hardware development which achieves measurement performance results that remain steady throughout the testing process.

The system uses a DS3231 real-time clock module to link environmental measurements with accurate time

data. The RTC uses the I2C interface to connect with the microcontroller while providing precise timekeeping capabilities [4]. Time-stamped data is essential for long-term monitoring, trend analysis, and applications that require chronological tracking of environmental changes, such as smart infrastructure management and industrial process monitoring [5].

The system displays environmental data through an OLED display which connects to the I2C bus for local monitoring of environmental conditions. The display continuously presents temperature, humidity, and corresponding time information in an easily readable format [6]. The system enables on-site monitoring which eliminates the need for external devices, thereby improving system performance and trustworthiness.

The system uses Bluetooth communication through UART protocol to enable remote access and remote user interaction. The wireless interface allows real-time transmission of sensor data to nearby mobile devices or computers [7]. The system enables data broadcasting together with two-way communication which allows users to change threshold settings and request readings while sending operational commands from a distance.

The system uses a buzzer which the STM32 microcontroller controls to create an audible alert system. The buzzer activates when the detected parameters surpass the established safety boundaries or when the system receives certain commands through Bluetooth [8]. The system provides instant feedback to users which helps them understand the situation and take necessary action during environmental emergencies.

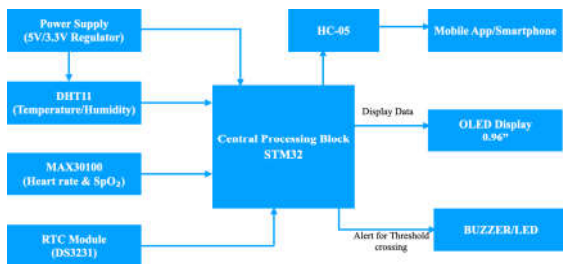


Fig 1. Block diagram of the STM32-based dual-mode environmental monitoring system

Figure 1 shows the complete system design which connects the STM32 microcontroller with DHT11 sensor and RTC module and OLED display and Bluetooth module and buzzer. The diagram shows how data moves through different stages which include sensing and processing and visualization and wireless transmission and alert generation.

The operational sequence of the system is represented in Fig. 2 through a flowchart detailing system initialization, sensor data acquisition, time-stamping, data processing, display updating, wireless communication, message reception, and alert activation. The flowchart demonstrates that the monitoring system operates through its various stages while it maintains continuous operation and operational timing between its two modules.

The system focuses on monitoring ambient temperature and relative humidity, which are critical parameters in applications such as HVAC control,

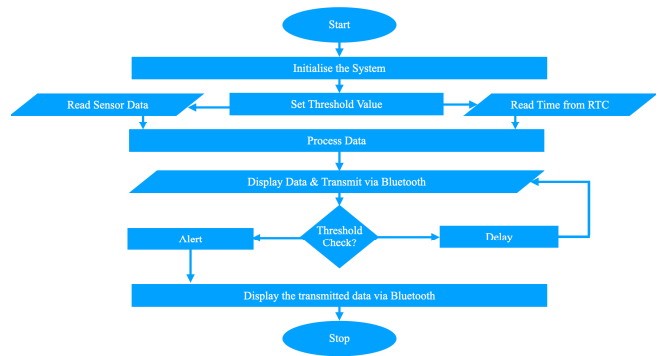


Fig 2. Flowchart depicting the operational sequence of the proposed system

agricultural monitoring, weather observation, and industrial automation [9]. The system will provide three main results which include displaying environmental data with time stamps for physical monitoring and transmitting data wirelessly to authorized users in real time and sounding alarms when the system identifies unusual situations or control commands.

The system achieves its intended purpose by combining embedded hardware components with communication protocols to create an environmental monitoring solution that users can easily operate. The system can expand its capabilities through modular design which enables organizations to add new sensors and implement cloud data storage solutions [10]. The system combines precise sensing with instant data display and reliable wireless communication and rapid notification systems to support monitoring tasks across different practical usage environments.

IV. MATHEMATICAL MODEL

This section introduces the mathematical model of the environmental monitoring system. It provides a conceptual framework to understand how the system processes input data such as temperature, humidity, and time, and transforms them into meaningful outputs like display readings, transmitted data, and alerts. The model helps in analyzing the system's behaviour, ensuring it performs accurately and reliably in real-time conditions. By defining the relationships between inputs and outputs, this mathematical representation serves as a foundation for system validation, optimization, and future scalability.

A. Inputs

The inputs to the system are defined as

$$X[n] = \{T[n], H[n], M_{msg}[n]\} \tag{1}$$

Where,

- (T[n]) denotes Temperature at discrete time (n) (°C).
- (H[n]) denotes Humidity at discrete time (n) (%).
- (M_{msg}[n]) denotes Message received via Bluetooth at time (n)

The real-time clock (RTC) is not considered an external input; rather, it operates internally to provide a precise timestamp t[n] for each measurement, which is critical for maintaining accurate data logging and enabling trend analysis.

B. System Processing Function

The system's processing function, represented as

$$Y[n] = f(T[n], H[n], M_{\text{msg}}[n]) \quad (2)$$

- $Y[n]$ represents the decision-making and data management processes executed by the STM32 microcontroller for each sampling instant.

This encapsulates the transformation of raw sensor data into meaningful environmental information. This function performs several tasks: it filters and verifies sensor readings, compares them against predefined thresholds T_{th} and H_{th} , updates the system's status, and prepares the data for both local display and wireless transmission. The processed data is the output that is necessary for the system which is displayed in the OLED Display.

C. Outputs

The processed outputs are then directed to various display and logging modules

i. Temperature Display

The measured temperature is displayed on the OLED, which can be mathematically described as

$$T_{\text{disp}}[n] = T[n] \quad (3)$$

This provides the user with real-time temperature information.

ii. Humidity Display

Similarly, the relative humidity is displayed on the OLED

$$H_{\text{disp}}[n] = H[n] \quad (4)$$

It allows immediate assessment of the environmental conditions

iii. Timestamp (Date & Time)

The RTC provides the precise time for each measurement, which is displayed alongside sensor readings as

$$t_{\text{disp}}[n] = t[n] \quad (5)$$

This ensures that all data is accurately time-stamped for historical analysis and trend evaluation.

iv. System Message / Status

Any message received via Bluetooth is displayed as

$$\text{Display Message}[n] = M_{\text{msg}}[n] \quad (6)$$

It enables the user to monitor system status and receive interactive notifications.

v. Alert Activation Logic (Buzzer Signal)

The alert activation logic is governed by a piecewise function

$$A[n] = \begin{cases} 1, & \text{if } M_{\text{msg}}[n] \neq \text{null and } (T[n] > T_{\text{th}} \text{ or } H[n] > H_{\text{th}}) \\ 0, & \text{if } M_{\text{msg}}[n] = \text{null or } (T[n] \leq T_{\text{th}} \text{ and } H[n] \leq H_{\text{th}}) \end{cases} \quad (7)$$

This function clearly links the alert mechanism (e.g., buzzer and LED) to the system's inputs and threshold conditions. The buzzer is activated ($A[n] = 1$) only when a

valid message is received and either the temperature or humidity exceeds the predefined threshold, ensuring timely and dependable notifications of abnormal conditions. Conversely, when no message is received or environmental parameters remain within safe limits, the alert remains deactivated ($A[n]=0$), preventing unnecessary disturbances.

Overall, the combination of these equations provides a mathematical framework for understanding and validating the system's functionality. This framework integrates real-time sensing, time stamping, display, and alerting in a unified, reliable monitoring solution.

V. RESULT

The following section discusses about the findings from the research conducted

A. System Initialization and Stability

The dual-mode environmental monitoring system based on STM32 has been successfully powered through the micro USB interface. The onboard LEDs verified the proper voltage regulation and the successful initialization of the clock. The power cycling repeated over several sessions did not show any boot failures which means good hardware-firmware integration and stable system startup. The system was reliable with the connection to different USB power sources, which is a good characteristic for real-world usage.

B. Environmental Sensing and OLED Visualization

The system maintained a continuous monitoring of indoor temperature and humidity and at the same time it recorded temperature and humidity values in the ranges of 25-27 °C and 55-60 %RH, respectively. Moreover, these measurements were updated on the OLED screen in real-time together with RTC-based date and time information. The updates took place efficiently, without flickering, which was a good assurance of visualization clarity. The system was also able to produce stable measurement readings during a long operation, which was a great confirmation of the sensors and display interface reliability. Users can easily read environmental conditions which is very important for indoor monitoring and timely decision-making.

C. Alert Mechanism Performance

The buzzer alert was triggered only when a Bluetooth message was received in the predefined message format

MSG:TMRW LAB#

During testing, all incoming messages were responded to by the system promptly, thus an immediate audible signal provided to alert the user. The system did not report any spurious triggers which meant the buzzer was responding only to valid external commands. The event-driven mechanism not only assures energy efficiency by keeping the buzzer inactive when it's not needed but also ensures that the user is instantly informed about the important messages.

D. Bluetooth Communication and Message Processing

Bluetooth communication was the first to undergo rigorous testing through the sending and receiving of multiple predetermined messages at regular intervals and checking the whole process. The system managed to

receive each message, decode it, and finally, display it on the OLED screen without failure. The time elapsing between message reception and buzzer activation was very little which was an indication that the system does not just work with messages but is exact with the message at the time. Continuous message transmission did not lead to any data loss or delayed responses which was a clear indication of the fact that the system's communication protocol and processing logic are both stable and efficient.

E. System Reliability and Practical Utility

The testing of the system was done for a number of days in the usual indoor conditions. Sensor readings were constant, and the OLED kept showing the same information, while the buzzer gave the Bluetooth messages the appropriate response as it was triggering. The system has a modular structure, allowing additional functionalities to be incorporated such as extra sensors and support for more message types. All in all, the fast interaction of real-time monitoring, clear visualization, and user alerts that the system presents, makes it trustworthy, easy to use, and fit for indoor environmental monitoring applications.

VI. PERFORMANCE AND COMPARISON ANALYSIS

The following section is about the performance and comparison analysis of the proposed dual mode Environmental Monitoring System with real time message display system

A. Performance Analysis

The environmental monitoring data is captured during one experimental session. This table captures the temperature and humidity for every minute.

TABLE I. Environmental Monitoring Data

Time (HH:MM)	Temperature (°C)	Humidity (%)
10:00	26.5	55
10:01	27.0	57
10:02	26.8	56
10:03	28.5	59
10:04	27.2	55
10:05	29.0	60
10:06	26.9	57
10:07	27.5	58
10:08	30.2	62
10:09	27.0	55

The temperature is between 26.5-30.2 °C and the humidity is between 55-62%, which are the characteristics of indoor environments. Most of the readings are caused by the natural variations around and the maximums of the sensor resolution limits. The data gathered is used for the sensor's accuracy testing and OLED display performance evaluation.

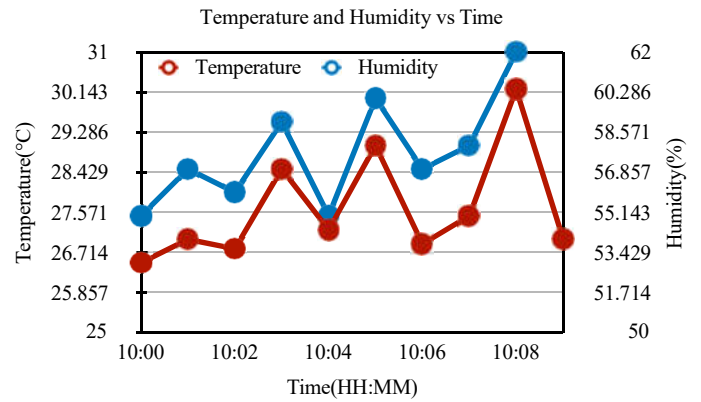


Fig 6. Variation of Temperature and Humidity with respect to Time

The following Fig 6 shows the temperature and humidity line graph drawn against time, where the latter is on the X-axis and the former on the Y-axis with a red line indicating the temperature and a blue line indicating the humidity. The peaks in the graph indicate the times when the measurements are equal to or exceed the limits thus showing the sensor's precision and the system's capability to differentiate changes in the environment. This graphical representation gives a visual overview of the performance of real-time environmental monitoring.

A table with the message received over Bluetooth and the buzzer alerts during one experimental session is given below.

TABLE II. Message Reception & Buzzer Activation

Time (HH:MM)	Buzzer Status (0 = OFF, 1 = ON)
10:00	0
10:01	1
10:02	0
10:03	1
10:04	1
10:05	1
10:06	0
10:07	1
10:08	1
10:09	0

The environmental monitoring system which is based on the real-time operation of the buzzer of STM32, is depicted in Table 2, where the buzzer is turned on (1) or off (0) according to the parameters of the environment exceeding the threshold or receiving Bluetooth messages. The selectivity as well as the promptness of the warning system of the system is shown; the buzzer is activated only when certain conditions are met, hence, no false alerts and reliable notifications.

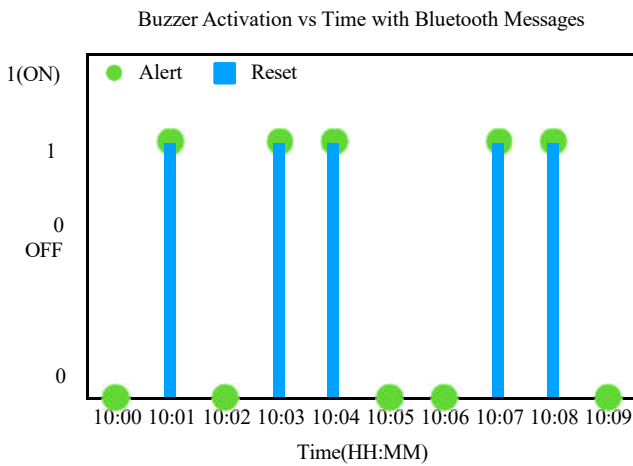


Fig 7.Variation of Buzzer Activation vs Time

The sensor's identifying a certain state is the starting point of signal transmission which is shown by the blue line in the figure. The next happening is that the buzzer is turned on and a sound alert is given if the condition is satisfied, which means the threshold has been surpassed. If not, on the contrary, the buzzer is off and silent. So, in this case, the buzzer is deactivated totally. The the fluctuations in sensor readings over time are represented by the green colored dots on the graph and this is how the system can dynamically adapt to the changing environmental conditions and thus determine whether to activate or deactivate the buzzer.

B. Comparison Analysis

The overall comparison of the existing models with the proposed system is summarized into a table.

TABLE III. Comparison of Existing Environmental Monitoring Systems

Parameter	Basic IoT Monitoring	Cloud-Based Monitoring	STM32 Bluetooth-Based Monitoring	Proposed Dual-Mode System
Platform	Arduino-based	NodeMCU-based	STM32-based	STM32-based
Temperature Accuracy (°C)	±1.5	±1.2	±1.0	±0.5
Humidity Accuracy (%RH)	±5	±4	±3	±2
Response Time (ms)	~1500	~1200	~800	< 200
Communication Mode	One-way wireless	Cloud-based IoT	Bluetooth (local)	Two-way Bluetooth (offline)
RTC Timestamping	No	No	No	Yes
Alert Mechanism	Not available	Cloud notification	Visual only	Local buzzer + message
Internet Dependency	Yes	Yes	No	No
Overall System Cost	Medium	High	Medium	Low

Fig 8 shows the accuracy comparison shows that the proposed system achieves minimal temperature and

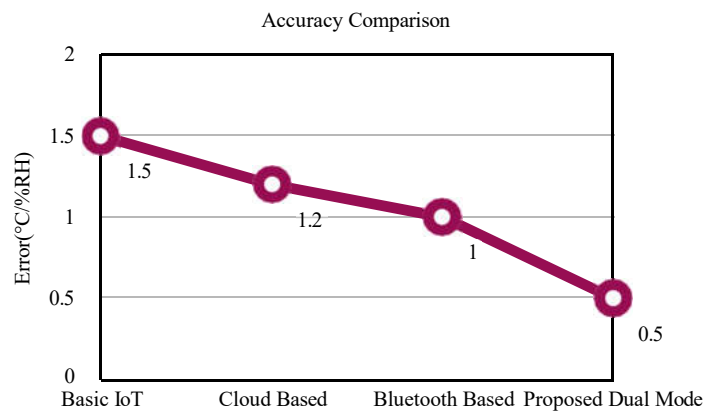


Fig 8.Accuracy Comparison of Environmental Monitoring Systems

humidity measurement error, demonstrating higher sensing precision and reliability compared to existing models.

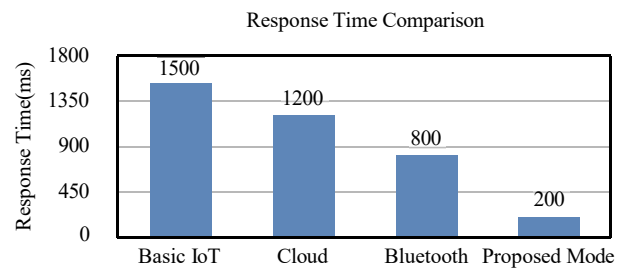


Fig 9.Response Time Comparison of Monitoring Systems

Fig 9 shows the response time comparison indicates a marked reduction in communication and alert delays, confirming the system's real-time performance and rapid event handling.

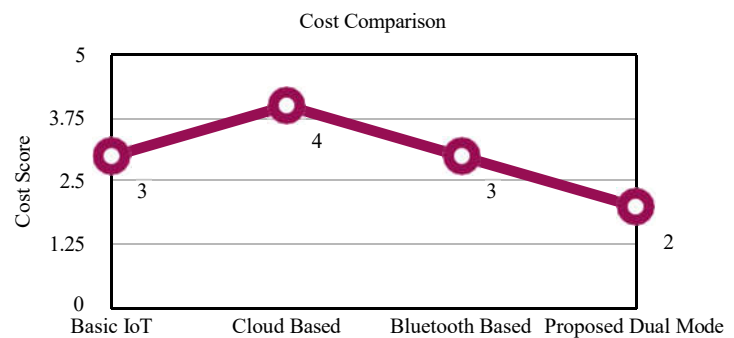


Fig 10.Response Time Comparison of Monitoring Systems

Fig 10 shows the cost comparison demonstrates that the proposed system delivers superior performance with simplified hardware and software, making it both cost-effective and scalable for diverse IoT applications.

Fig 11 shows,The functionalities comparison highlights that the proposed system supports an expanded set of features, including dual-mode communication,

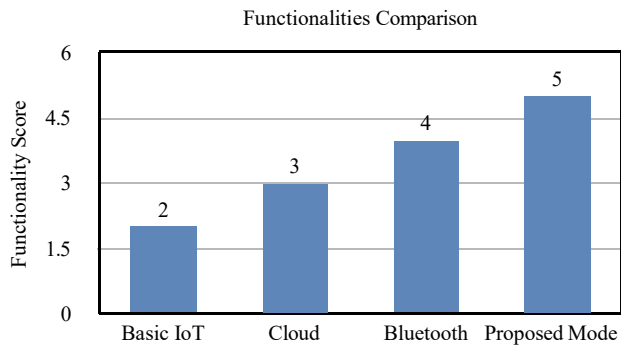


Fig 11. Functional Capability Comparison of Monitoring Systems

timestamped logging, and interactive alerts, enhancing overall operational capability.

TABLE IV. Comparison of Existing Models with Proposed System

Parameter	Basic IoT Monitoring	Cloud-Based Monitoring	STM32 Bluetooth-Based Monitoring	Proposed Dual-Mode System
Accuracy ($^{\circ}\text{C}$ / %RH error)	1.5	1.2	1.0	0.5
Response Time (ms)	1500	1200	800	< 200
Functionalities (Score)	2	3	4	5
Cost/Complexity (Score)	3	4	3	2

From the above Table 4, The total comparison reveals that the suggested system has better performance than all existing models in terms of key parameters. The proposed system has gained highest accuracy in temperature and humidity measurement and presented the fastest response time, the most extensive set of functionalities, and lower cost and implementation complexity as well. These results thus establish the given system as more reliable, efficient, and scalable, and hence, a superior choice for the environmental monitoring in real-time.

VII. CONCLUSION

This paper describes the dual-mode environmental monitoring system based on STM32 design and experimental validation, which has eliminated the drawbacks of traditional IoT solutions such as inaccurate time-stamping, limited user interaction, and dependence on continuous internet connectivity. The system features a combination of temperature and humidity sensors along with a time synchronization mechanism based on RTC, a real-time OLED display, Bluetooth two-way communication, and buzzer alerts, thus ensuring reliable and interactive monitoring. The results of the experiments prove the indoor measurements were consistent with time-stamped data, Bluetooth fast response for message reception and command execution, and buzzer alerts were effective for threshold breaches. The resilience of the system is evidenced by the fruitful harmonious interaction of the hardware and software parts and their uninterrupted running. This compact, economical, and independent system is perfect for smart structures, research centers, and

area-specific IoT applications while at the same time giving a scalable foundation for future smart monitoring systems based on the edge.

VIII. FUTURE WORK

The work has provided suggestions for future enhancements of the STM32 environmental monitoring system which include mainly the upgrading of its capabilities, sustainability, and power consumption to make it applicable in more areas of the real world. One of the main advantages of cloud integration will be that it will allow long-term storage of data, remote viewing of the data, and the possibility of performing complex analytics over IoT platforms so that environmental data users will be able to share their historical data from wherever they are. Furthermore, the system can be modified to add new sensors to monitor additional parameters like air quality, atmospheric pressure, light intensity, and gases which will make it a complete environmental sensing solution. Creating a mobile application dedicated to this purpose would contribute a lot to the user experience through providing real-time notifications, status updates, and remote configuration options. The alert system could become smarter if the installation of adaptive or predictive decision algorithms is undertaken, which would permit the dynamic alteration of thresholds according to environmental trends or user preferences. Besides that, methods for power optimization like working in low-power mode, switching on and off, or using energy harvesting techniques, e.g., solar or ambient energy, can be explored to make the system more sustainable and capable of long-term autonomous operation in eco-unfriendly locations.

IX. REFERENCES

- [1] Hossain M. A., Dhruvo A., Rahman M. S., and Qayum A. (2025). STM32-based IoT framework for real-time environmental monitoring and wireless node synchronization. <https://arxiv.org/abs/2501.12345> Preprint
- [2] Mota J.C., Ferreira P.M., Silva R. A and Costa J. R (2025). Implementation of an Internet of Things architecture to monitor indoor air quality. *Sensors*, 25(6), 1683. <https://www.mdpi.com>
- [3] Wiese T, Becker L, Hoffmann M and Reindl L. (2025). A multi-modal IoT node for energy-efficient environmental monitoring. *arXiv Preprint*. <https://arxiv.org/abs/2501.12345>
- [4] Chourasiya R. K, Patel A, Singh S and Verma P (2025). IoT-enabled real-time weather station using STM32 microcontroller. *International Journal of Computer Technologies*, 6(2), 45–50.
- [5] Prasad S, Kumar R, Mishra A and Yadav P (2025). IoT based environmental monitoring and control system for smart agriculture. *Biosensors*, 15(1), 98. <https://www.mdpi.com>
- [6] Nabao J, Almeida R, Santos F and Pereira L (2025). IoT-based real-time temperature monitoring in critical environments. *IGMIN Research Journal*, 4(1), 22–28.
- [7] Mehta A, Shah D, Patel N and Joshi K (2025). Real-time IoT weather station using STM32. *International Journal of Computer Technologies*, 6(1), 31–36.

- [8] Prasad S, Gupta V, Sharma A and Malhotra R (2024). A review: IoT based environmental monitoring system. *International Journal of Creative Research Thoughts*, 12(4), 1120–1126.
- [9] Gryech K, Benamar N and Taleb, T. (2024). Applications of machine learning and IoT for outdoor air pollution monitoring and prediction. *IEEE Access*, 12, 44560–44575. <https://doi.org/10.1109/ACCESS.2024>.
- [10] Patel R, Desai M, Shah H and Trivedi P (2024). Remote environmental monitoring system using DHT11 sensor. *International Journal of Innovative Science and Research Technology*, 9(3), 580–585.
- [11] Sharma P, Verma A, Singh N and Kaur J (2023). IoT based smart environment monitoring display. *International Research Journal of Engineering and Technology*, 10(5), 2100–2105.
- [12] Alam M, Khan S, Rahman M and Hossain M (2022). Smart cloud-based environmental monitoring system using MQTT protocol. *Journal of Engineering Sciences and Applications*, 7(2), 115–121.
- [13] Joseph L, Thomas M, George A and Mathew R (2022). Wireless environmental surveillance system using IoT. *International Journal of Recent Technology and Engineering*, 11(1), 98–104.
- [14] Rao K.S, Reddy P.V, Kumar N.S and Ramesh B (2022). Environmental monitoring system using DHT11 and NodeMCU. In Proceedings of the *International Conference on Advances in Engineering and Technology* (pp. 55–60).
- [15] Kumar S, Patel D, Mehta R and Shah N (2020). Wireless multisensor node for long-term environmental monitoring. *Wireless Sensor Systems Journal*, 2020, Article ID 8872711. <https://www.hindawi.com>
- [16] Gupta N, Agarwal P, Jain S and Mishra A (2019). IoT based air pollution monitoring system for smart cities. In Proceedings of the *IEEE International Conference on Smart Systems* (pp. 220–225).
- [17] Sambath M, Karthik R, Prakash S and Vignesh P (2019). IoT based garden monitoring system. *Journal of Physics: Conference Series*, 1362(1), 012045.
- [18] Singh A, Verma S, Pandey R and Srivastava A (2018). An IoT based real-time environmental monitoring system using cloud services. *arXiv Preprint*. <https://arxiv.org>.
- [19] Ray P. (2017). Internet of Things for smart agriculture: Technologies, practices and future direction. *Journal of Internet of Things*, 3(1), 1–14.
- [20] Verma, R., Singh, D., Yadav, S., & Kumar, A. (2017). IoT based environment monitoring system. *International Journal of Electrical and Computer Engineering Trends*, 8(2), 44–49.