

IoT Based Environmental Monitoring System for Residential Building with LoRa Technology

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Abstract

This paper introduces an environmental monitoring system for residential buildings that combines PIC microcontroller functionality with LoRa technology. The system integrates motion, flame, gas, vibration, temperature, and humidity sensors to provide real-time monitoring of environmental conditions and safety risks. The PIC microcontroller acts as the system's core, gathering and processing data from the sensors before transmitting it over a LoRa network to a remote station. LoRa technology is employed for its long-range and low-power communication capabilities, making the system energy-efficient and reliable for residential applications. By delivering timely alerts and insights into potential hazards, this system enhances safety and livability in residential settings. The results highlight the practicality of the proposed design and its potential for integration into smart building applications, offering a scalable and efficient solution for modern environmental monitoring challenges.

A. Introduction

The Internet of Things (IoT) has transformed environmental monitoring, particularly in residential buildings, by enabling real-time data collection and communication. Traditional systems face challenges such as high costs and range limitations, which LoRa technology overcomes with its low-power, long-range capabilities. This paper presents an IoT-based environmental monitoring system that integrates sensors for temperature, humidity, gas levels, and motion, transmitting data via LoRa to a remote monitoring station for real-time analysis. With increasing adoption in smart building management and industrial automation, LoRa-based IoT solutions offer cost-effective and sustainable monitoring. This research aligns with industry trends in smart cities and sustainable housing, addressing challenges like energy efficiency and data reliability, with applications extending to industrial safety, healthcare, and smart agriculture.

Environmental monitoring systems play a vital role in ensuring safety and comfort in residential settings, with extensive research focusing on integrating microcontrollers, wireless communication protocols, and sensors. PIC microcontrollers are widely recognized for their efficiency and adaptability in real-time data processing, while LoRa technology has gained prominence for its long-range, low-power communication, making it ideal for IoT applications. Studies have demonstrated the utility of individual sensors for detecting motion, flame, gas, vibration, temperature, and humidity; however, many existing systems fail to unify these sensors into a comprehensive, energy-efficient solution. This research addresses the gap by integrating PIC microcontrollers and LoRa technology with a diverse sensor array to develop a scalable and robust environmental monitoring system for residential buildings.

System [1] has demonstrated the effectiveness of hardware implementations using Arduino Uno microcontrollers, ACS712 current sensors, and XBee-PRO ZigBee modules for real-time load monitoring. The multi-hop networking capability of ZigBee further enhances communication reliability and range in residential environments. These systems [2] often utilize Arduino Mega 2560 microcontrollers for sensor data acquisition, NodeMCU ESP8266 for wireless communication, and Raspberry Pi microcomputers for decision-making, with locally hosted Node-RED dashboards providing user-friendly interfaces. The Message Queuing Telemetry Transport (MQTT) protocol is commonly employed for reliable Wi-Fi communication.

Unlike traditional methods designed for office spaces, this concept supports an unlimited number of individual sensor configurations, enabling greater flexibility. By incorporating sensors to monitor environmental factors such as temperature, fire, gas, vibration, and humidity, and utilizing PIC microcontrollers for data acquisition and processing, LoRaWAN-based BMS offers a reliable and efficient framework. These advancements demonstrate the feasibility of implementing scalable, automated monitoring systems in diverse building environments [3].

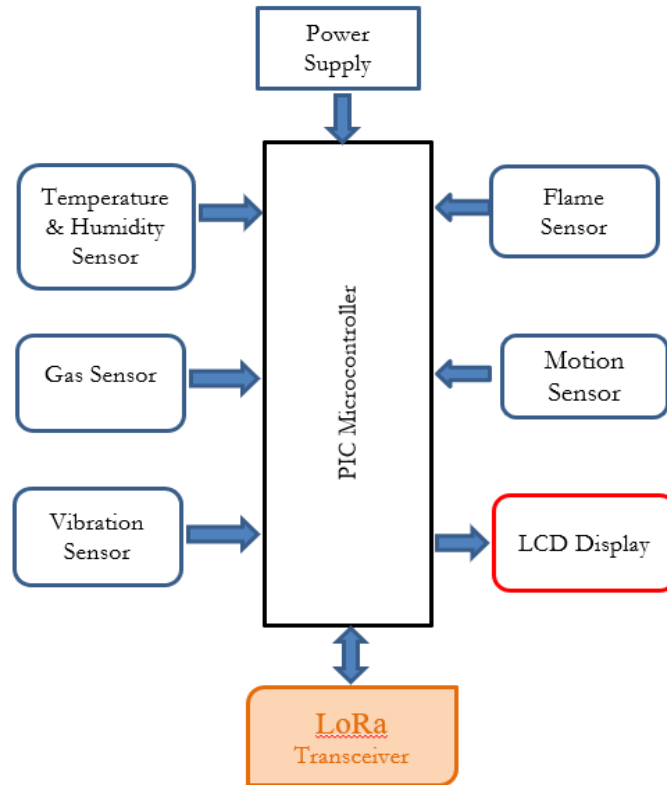


Figure 1. Block Diagram of Control Unit at Target Building

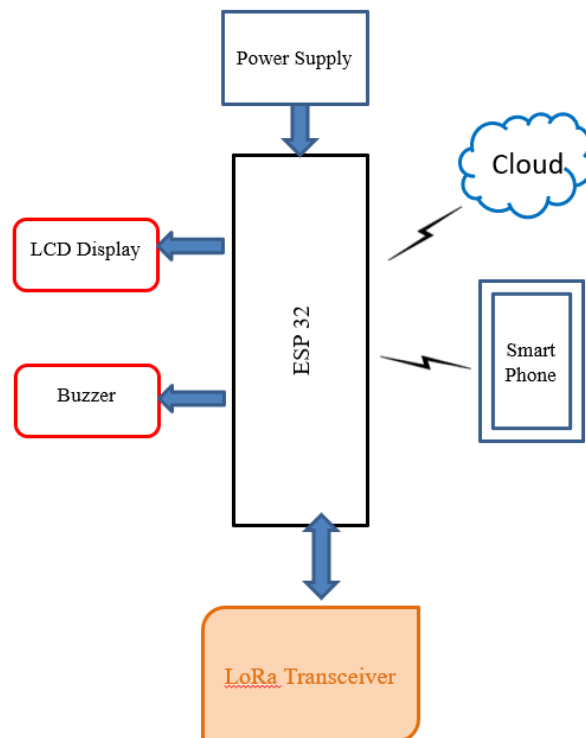


Figure 2. Block Diagram of Control Unit at Remote Building

B. Research Methodology

This research employs a comprehensive experimental and analytical approach to systematically design, develop, and evaluate an IoT-based environmental monitoring system utilizing LoRa technology for residential buildings. The study follows a structured methodology that includes hardware selection, system architecture design, firmware development, and performance evaluation to ensure efficient and reliable data transmission over long distances. The research further emphasizes real-world deployment scenarios, analyzing how environmental factors such as obstacles, interference, and signal attenuation impact LoRa's effectiveness in a residential setting.

The system integrates a diverse range of environmental sensors including temperature, humidity, gas, flame, motion, and vibration sensors to comprehensively monitor indoor environmental conditions. These sensors are interfaced with microcontrollers such as PIC16F887 for data acquisition and ESP32 for LoRa-based wireless transmission, enabling real-time communication. LoRa RA-02 modules facilitate long-range, low-power data transmission, making the system highly suitable for applications requiring extended coverage with minimal energy consumption. The embedded firmware is designed to optimize data collection, transmission scheduling, and power efficiency, ensuring the system operates effectively in continuous monitoring scenarios.

The collected environmental data is processed, transmitted, and securely stored in a cloud database, enabling seamless remote monitoring through a web-based dashboard or mobile application. The system architecture supports real-time data visualization, alert mechanisms, and historical trend analysis to enhance decision-making and user interaction. Furthermore, cloud integration ensures data accessibility, redundancy, and scalability, allowing multiple users to monitor environmental conditions from various locations.

Table 1. List of components

No	Name	Quantity
1	PIC16F887 microcontroller	1 Nos
2	ESP32 microcontroller	1 Nos
3	Temperature and Humidity Sensor	1 Nos
4	Motion Sensor	1 Nos
5	Flame sensor	1 Nos
6	Gas sensor	1 Nos
7	Vibration sensor	1 Nos
8	LCD display	3 Nos
9	Buzzer	2 Nos

System Hardware Deployment

This section focuses on the physical setup and integration of various components, such as the PIC microcontroller, LoRa communication modules, and multiple environmental sensors. The system is designed to monitor critical environmental parameters, including motion, flame, gas, vibration, temperature, and humidity. Each sensor is interfaced with the PIC microcontroller, which acts as the central processing unit, responsible for collecting sensor data, processing it, and transmitting the information over the LoRa network to a remote monitoring station. The hardware setup also includes power management components to

ensure the system operates efficiently, with minimal energy consumption. The use of LoRa technology enables long-range, low-power communication, making it ideal for residential applications. This section details the configuration and interconnection of the hardware components, along with the testing and calibration of the sensors to ensure accurate and reliable data collection.

PIC Microcontroller

The PIC16F887 is an 8-bit microcontroller from Microchip Technology, known for its versatility and power efficiency, making it ideal for embedded systems. It features 368 bytes of RAM, 14KB of Flash memory, and a 10-bit ADC with up to 14 input channels, which is useful for sensor integration. With built-in communication protocols like USART, SPI, and I2C, it supports easy interfacing with external devices and modules. The microcontroller also offers PWM capabilities, timers for time-sensitive tasks, and low power consumption, making it suitable for battery-operated applications [4].



Figure 3. PIC 16F887 microcontroller [4]

ESP32 Microcontroller

The ESP32 is a powerful, dual-core 32-bit microcontroller from Espressif Systems, designed for IoT applications. It features built-in Wi-Fi and Bluetooth connectivity (Classic and BLE), making it ideal for wireless communication in various projects. The microcontroller offers a 240 MHz dual-core processor, 520 KB of SRAM, and support for external flash memory, providing high performance and ample storage. It also includes a range of peripherals like ADC, DAC, PWM, and hardware encryption for secure communication. With its low power consumption and various energy-saving modes, the ESP32 is well-suited for battery-powered IoT devices [5].



Figure 4. ESP32 microcontroller [5]

Ra-02 AI-Thinker SX1278 LoRa Socket Module

The RA-02 AI-Thinker SX1278 LoRa Socket Module is a long-range, low-power wireless communication module that uses LoRa (Long Range) technology, ideal for IoT applications. Operating in the 433 MHz frequency band, it offers communication ranges up to 5-10 km in open areas. With high sensitivity (-148 dBm) and strong output power (+20 dBm), it provides reliable data transmission over long distances. The module integrates a power amplifier (PA) and low noise amplifier (LNA) for enhanced signal quality and supports SPI communication for easy integration with microcontrollers [6].

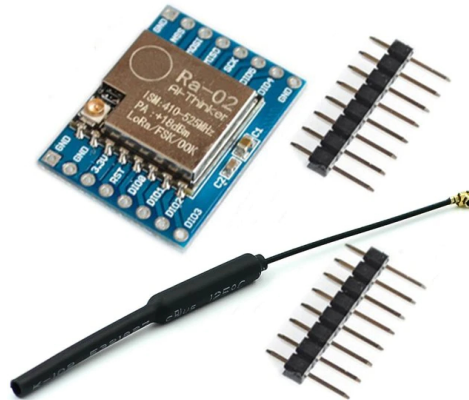


Figure 5. Ra-02 Lora socket module [6]

IR Flame Sensor Module

The IR Infrared Flame Sensor Module detects flames by sensing the infrared radiation (typically between 760 nm and 1,100 nm) emitted by a fire. It consists of an IR photodiode, a high-gain amplifier, and a comparison circuit, providing a digital output (HIGH or LOW) based on flame detection. Commonly used in fire alarm systems, gas burners, fire-fighting robots, and safety applications, the sensor is low power, compact, and offers quick detection of flames. However, it may trigger false alarms due to other infrared radiation sources and has a limited detection range. Its effectiveness in providing early fire detection makes it an essential component for safety systems [7].



Figure 6. Flame sensor module [7]

PIR Motion Sensor Module

The PIR (Passive Infrared) Motion Sensor Module detects motion by sensing infrared radiation emitted by warm objects, such as humans or animals. It includes a pyroelectric sensor, lens, and amplifier circuit, providing a digital output when motion is detected. Commonly used in security systems, automatic lighting, and home automation, the module is low power, easy to interface with microcontrollers. While it is affordable and compact, the sensor may have limited detection areas and can be affected by environmental factors, leading to potential false alarms [8].



Figure 7. Motion sensor module [8]

Temperature and Humidity Sensor

The DHT11 is an affordable and commonly used sensor for measuring temperature and humidity. It offers a digital output for both readings, with a temperature range of 0°C to 50°C and humidity range of 20% to 90% RH, with moderate accuracy. The sensor uses a simple single-wire digital interface, making it easy to connect with microcontrollers [9].

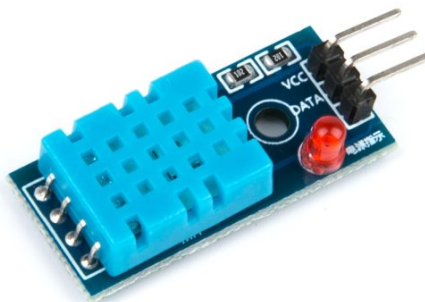


Figure 8. Temperature and humidity sensor module [9]

MQ2 Gas Sensor Module

The MQ2 Gas Sensor Module is a versatile sensor used to detect various gases such as methane, carbon monoxide, smoke, and propane. It works by measuring the change in resistance of a gas-sensitive material when it interacts with gases, providing both analog and digital output signals. Commonly used in gas leak detection, smoke detection, and air quality monitoring, the MQ2 is affordable, easy to interface with microcontrollers like Arduino and ESP32, and suitable for a wide range of applications. However, it requires calibration, has a limited lifespan, and consumes more power due to its heating element [10].

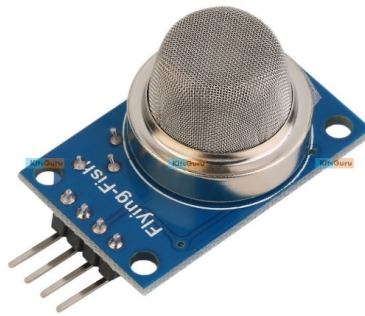


Figure 9. Gas sensor module [10]

Vibration Sensor Module

The Vibration Sensor Module is designed to detect mechanical vibrations or movements in an environment. It typically uses a piezoelectric or MEMS (Micro-Electro-Mechanical Systems) sensor to convert vibrations into an electrical signal. The module provides a digital output (HIGH or LOW) indicating the presence of vibrations above a certain threshold. It is widely used in applications such as security systems for detecting unauthorized movement, industrial machinery monitoring to detect faults or malfunctions, and earthquake detection. The sensor is easy to interface with microcontrollers like Arduino or ESP32 and is valued for its low cost, simplicity, and effectiveness in detecting vibrations in various environments. However, it can be sensitive to both mechanical and environmental factors, leading to potential false readings [11].



Figure 10. Vibration sensor module [11]

LCD Display

A 20x4 LCD Display is a type of Liquid Crystal Display (LCD) that can display 20 characters per line on 4 lines, providing a total of 80 characters of display space. It is commonly used in embedded systems, Arduino projects, and IoT applications for displaying text, sensor data, and other user information. Known for its low power consumption, compact size, and ability to display multiple lines of text, the 20x4 LCD is widely used in user interfaces, real-time monitoring systems, and home automation projects, offering a clear and readable output for users. Its simplicity and versatility make it a popular choice for projects requiring text-based interaction [12].



Figure 11. LCD display [12]

Buzzer

A buzzer is an electronic component used to produce sound, often for signaling or alert purposes in various electronic systems. It typically consists of a piezoelectric element or an electromagnetic coil that vibrates when powered, creating audible sound. Buzzers can be activated by a digital output from a microcontroller and are widely used in alarm systems, notifications, and indicators to alert users to a particular event, such as a warning or error [13].



Figure 12. Buzzer module [13]

C. Circuit Configuration

The building monitoring system operates by using a PIC microcontroller to gather data from various sensors, including temperature, gas, vibration, flame, and motion sensors, which monitor environmental and safety parameters. The collected data is displayed locally on an LCD screen and transmitted wirelessly using a LoRa transceiver to an ESP32 microcontroller located remotely. The ESP32 processes the received data and uploads it to a cloud platform for remote access and analysis. Additionally, an alert system can be integrated to notify users via mobile applications or email in case of abnormal environmental conditions, ensuring proactive monitoring and response.

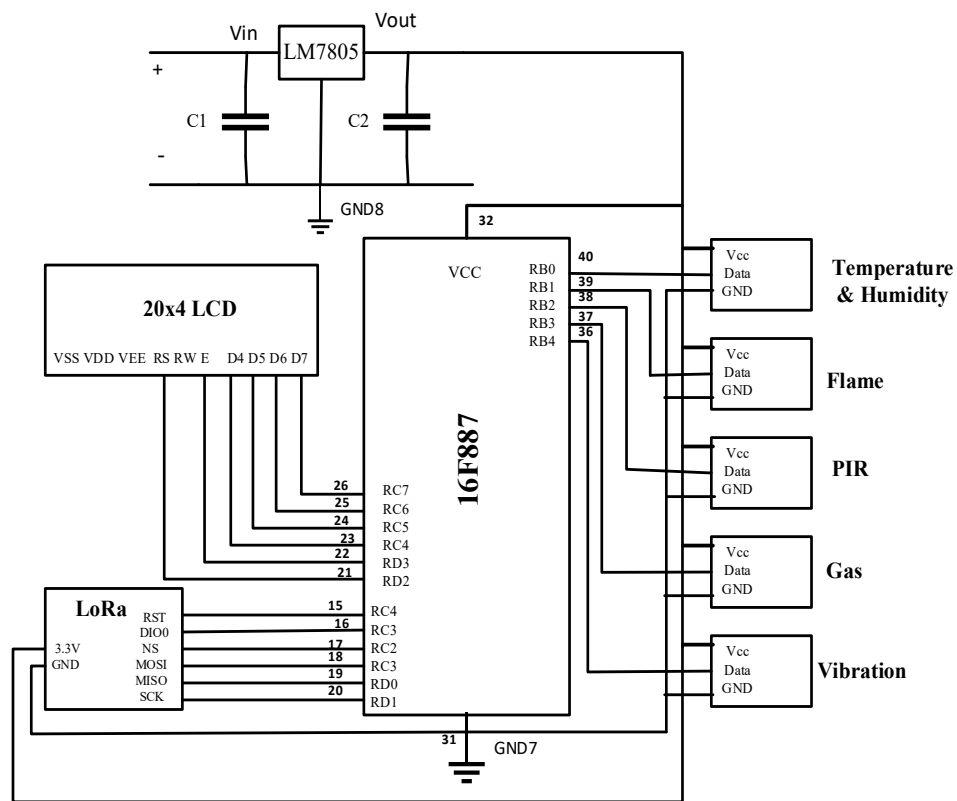


Figure 13. Circuit diagram of control unit at target building

The ESP32 processes the received data, displays it on another LCD screen, and activates a buzzer for alarms in case of critical conditions. Both circuits are powered by their respective power supplies, and the LoRa transceivers enable long-range communication, ensuring efficient monitoring and timely alerts.

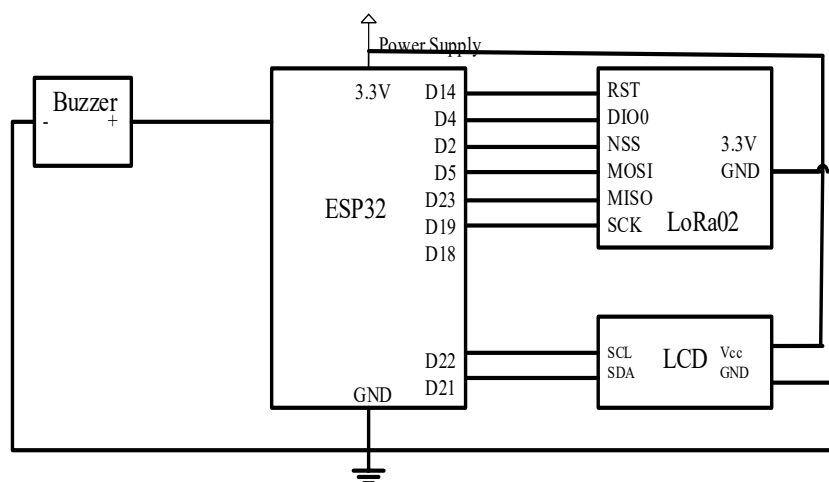


Figure 14. Circuit diagram of control unit at remote building

D. System Software Deployment

System Software Deployment for a building monitoring system involves the integration, configuration, and programming of software components to enable effective monitoring and control of building parameters. This process utilizes the BasicPro programming language to program the PIC microcontroller, which serves as the core of the system, managing inputs from sensors that monitor temperature, gas levels, vibrations, flames, and motion. The deployment ensures seamless communication between the hardware components and the LoRa transceivers for long-range data transmission. Additionally, it includes the setup of user interfaces such as LCD displays for real-time monitoring and alerts through actuators like buzzers. By leveraging the simplicity and efficiency of BasicPro for microcontroller programming, the deployment streamlines system operation, ensuring reliability and enhanced safety in building management.

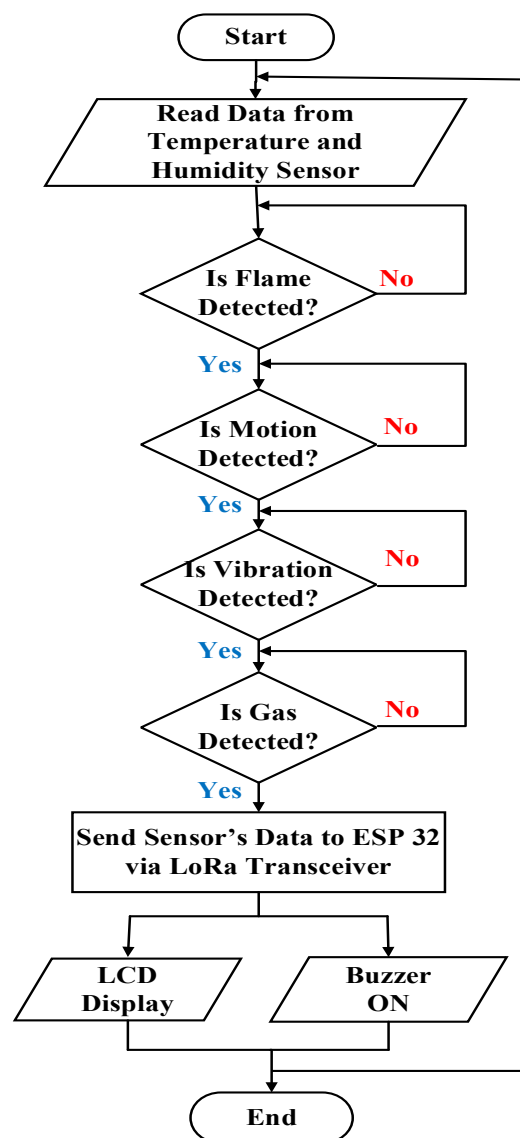


Figure 15. Flow chart of control unit at target building

The flowchart outlines the sequential decision-making process of a building monitoring system, which evaluates inputs from multiple sensors, including temperature, gas, vibration, flame, and motion sensors. At each step, the system checks whether the monitored parameter exceeds a predefined threshold. If a critical condition is detected, appropriate actions such as triggering alarms, displaying alerts on an LCD, or sending data to a remote system are taken. If no issues are detected, the system continues monitoring other parameters. This systematic approach ensures efficient detection and response to potential hazards, enhancing building safety and management.

The flowchart depicts the operation of a LoRa-based monitoring system, starting with the initialization and reading of incoming data from the LoRa module. If no data is received, the system continues to wait and monitor for updates. When valid data is received, it is displayed on an LCD for real-time monitoring, and a buzzer is activated if the data indicates an alarm condition. This simple yet effective process ensures timely responses to critical events and provides continuous monitoring of building parameters.

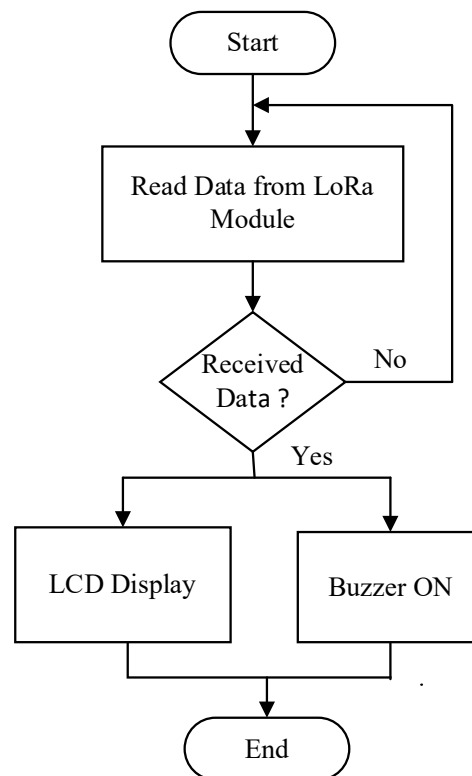


Figure 16. Flow chart of control unit at remote building

E. Test and Result

This section presents the experimental setup and results of the performance evaluation for the proposed environmental monitoring system designed for residential buildings using LoRa technology. The system incorporates a DHT11 sensor to measure both temperature and humidity. During testing, the sensor

provided readings of 28.00°C for temperature and 53.00% RH for humidity, which were displayed on the LCD screen shown in Figure (17).

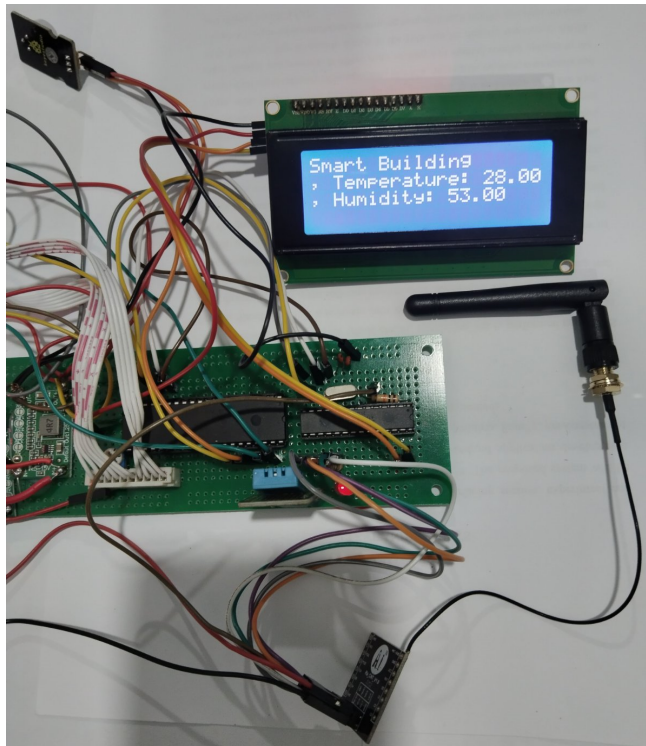


Figure 17. Experiment of temperature and humidity sensor at target building

The test results of the temperature and humidity sensor (figure 18) at the remote site were successfully displayed on the LCD, showing a temperature of 28.00°C and humidity of 53.00% RH, confirming accurate data transmission and proper functionality of the remote monitoring system.



Figure 18. Experiment of temperature and humidity sensor at remote building

Figure (19) illustrates the test and result of the motion sensor at the target building. The setup includes an LCD screen displaying the detection status of motion and vibration, with the system confirming "MOTION" detected.

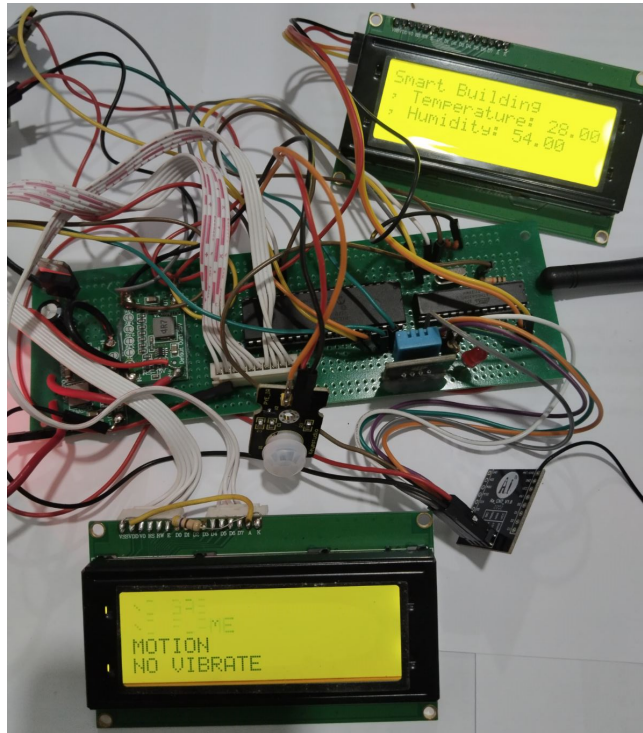


Figure 19. Experiment of motion sensor at target

Figure (20) shows the test and result of the motion sensor at the remote building. The LCD display indicates the motion sensor's status, confirming the detection of "Motion detect".



Figure 20. Experiment of motion sensor at remote building

Figure (21) illustrates the test and result of the flame sensor at the target building. The setup includes an LCD screen displaying the detection status of flame, with the system confirming "FLAME" detected.

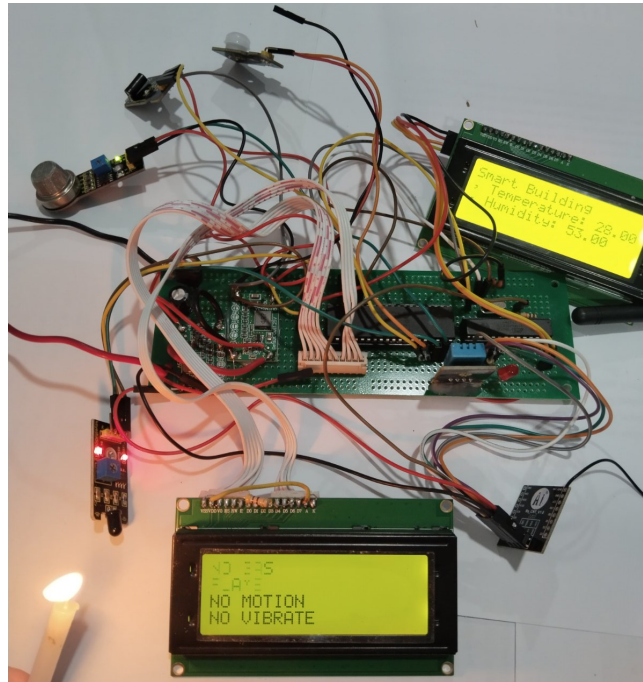


Figure 21. Experiment of flame sensor at target building

Figure (22) shows the test and result of the flame sensor at the remote building. The LCD display indicates the flame sensor's status, confirming the detection of "Flame detect".



Figure 22. Experiment of flame sensor at remote building

Figure (23) illustrates the test and result of the vibration sensor at the target building. The setup includes an LCD screen displaying the detection status of vibration, with the system confirming "VIBRATE" detected.

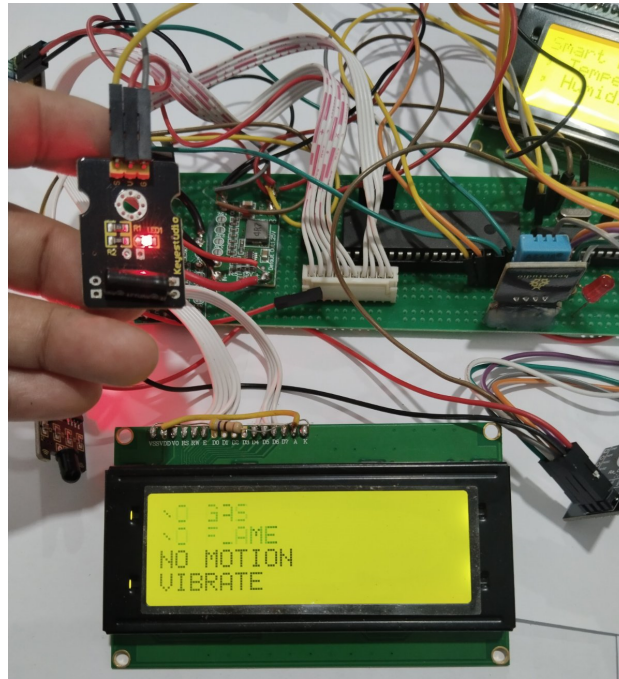


Figure 23. Experiment of vibration sensor at target building

Figure (24) shows the test and result of the vibration sensor at the remote building. The LCD display indicates the vibration sensor's status, confirming the detection of "Vibration detect".



Figure 24. Experiment of vibration sensor at remote building

Figure (25) illustrates the test and result of the gas sensor at the target building. The setup includes an LCD screen displaying the detection status of gas, with the system confirming "GAS" detected.

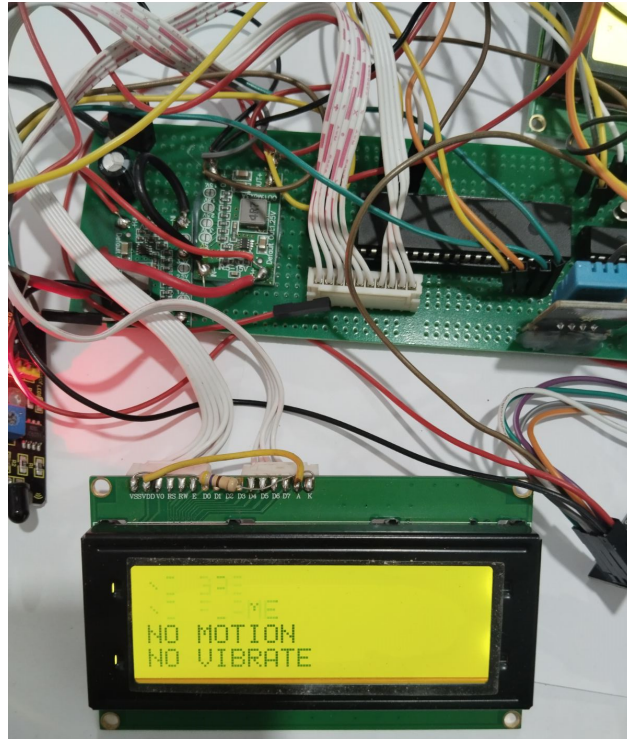


Figure 25. Experiment of gas sensor at target building

Figure (26) shows the test and result of the gas sensor at the remote building. The LCD display indicates the gas sensor's status, confirming the detection of "Gas detect".



Figure 26. Experiment of gas sensor at remote building

Figure (27) shows a Blynk.Console dashboard for a "Smart Building" project using LoRa technology. It displays live data for temperature and humidity and includes a switch control.

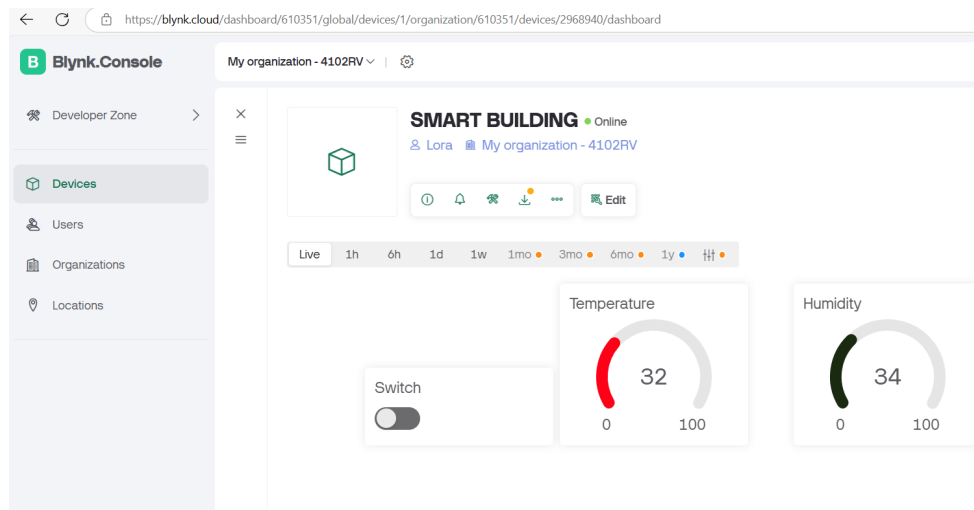


Figure 27. Temperature and humidity data in real time

The figure (28) represents a Blynk.Console dashboard for a Smart Building application. It displays the status of critical safety parameters monitored via LoRa-connected sensors. The key feature in the figure is the "Gas Detected" field, which currently shows "Yes", indicating the presence of a gas leak or hazardous gas levels.

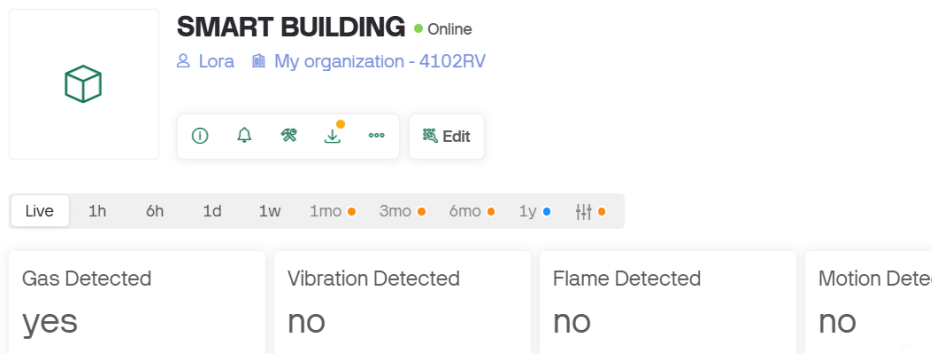


Figure 28. Detection of gas sensor in real time

The figure (29) represents a Blynk.Console dashboard for a Smart Building application, focusing on safety monitoring via LoRa-connected sensors. The critical feature in this figure is the "Flame Detected" field, which currently shows "Yes", indicating the presence of a fire or heat source. This real-time interface ensures quick identification of fire-related incidents, allowing for immediate response and mitigation.

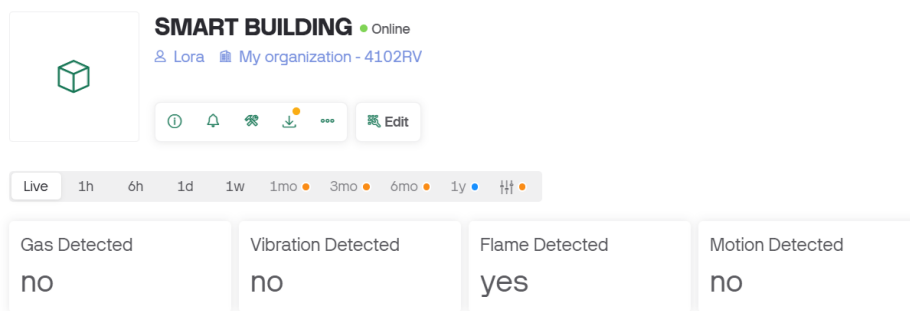


Figure 29. Detection of flame sensor in real time

The figure (30) represents a Blynk.Console dashboard for a Smart Building application, focusing on safety and security monitoring using LoRa-connected sensors. The critical feature in this figure is the "Motion Detected" field, which currently shows "Yes", indicating that motion or unauthorized movement has been detected within the monitored area. This real-time status highlights a potential security concern, prompting further investigation or action to ensure the safety of the building.

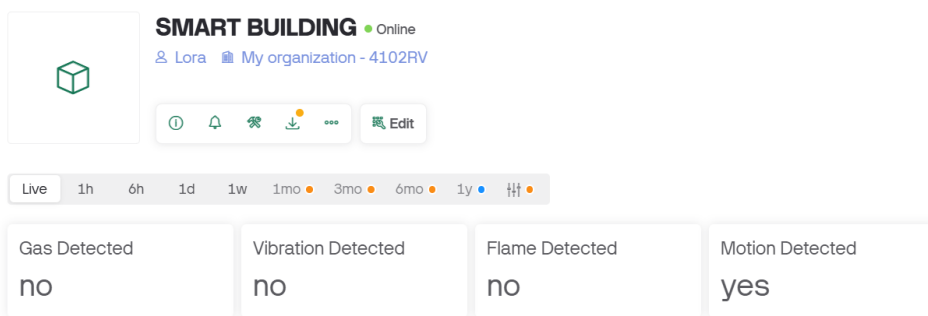


Figure 30. Detection of motion sensor in real time

The figure (31) represents a Blynk.Console dashboard for a Smart Building application, showcasing real-time safety monitoring using LoRa-connected sensors. The key feature in this figure is the "Vibration Detected" field, which currently shows "Yes", indicating that abnormal vibrations or structural instability have been detected.

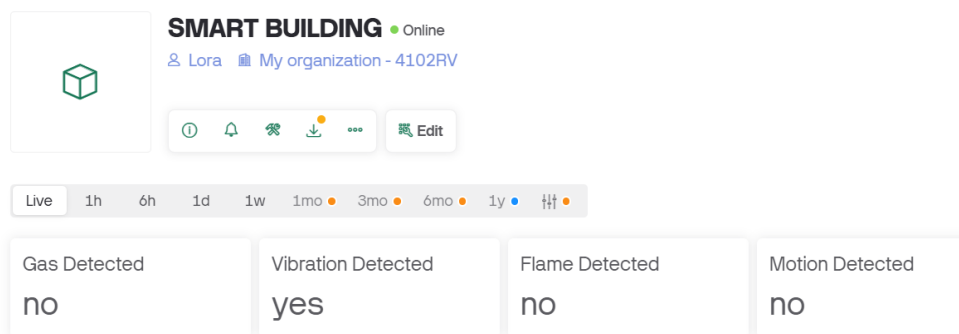


Figure 31. Detection of vibration sensor in real time

F. Conclusion

The system provides reliable long-distance communication, making it highly suitable for large residential or industrial environments. The LoRa network ensures long-range, low-power communication, making it ideal for residential monitoring. LoRa socket modules and the tested communication range is around 500~600 m (none line of sight). The module maintain communication over long distances, especially in line-of-sight scenarios. However, real-world factors like interference, antenna quality, and environmental obstacles may reduce the effective range. The system is energy-efficient, scalable, and well-suited for wide-area monitoring, though challenges such as signal interference and data latency need to be considered for future improvements.

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H. References

- [1] Mohammed Abo-Zahhad, Sabah M. Ahmed, Mohammed Farrag, Mohammed F. A. Ahmed and Abdelhay Ali, "Design and implementation of building energy monitoring and management system based on wireless sensor networks," *Conference Paper, Research Gate*, December 2015, doi: 10.1109/icces.2015.7393051
- [2] Muhammad Uzair, Karam Manaf Al-Janadi, Salah Yacoub Al-Kafrawi and Ibrahim Abdulrahman Al-Bulushi, "A low-cost IoT based buildings management system (BMS) using arduino mega 2560 and raspberry pi 4 for smart monitoring and automation," *International Journal of Electrical and Computer Engineering Systems*, vol. 13, Number 3, 2022, pp. 219-236.
- [3] K.Sangeetha , R.Lakshmid devi V.Chitra and K.Sivasankari, "Lora wan based building management and monitoring system," *Ilkogretim online - elementary education online*, 2020; Vol 19 (Issue 4): pp. 6567-6576
- [4] Microchip, "PIC1F887 datasheet," Available: <https://www.microchip.com/enus/product/pic16f887>
- [5] Espressif, "ESP32 series," version 4.7, Available: https://www.espressif.com/sites/default/files/documentation/esp32_datasheet_en.pdf
- [6] Ai-Thinker, "Ra-02 lora module," v1.1, Available: https://docs.aithinker.com/media/lora/docs/c04_8ps01a1_ra-02_product_specification_v1.1.pdf

- [7] H. Wang, X. Zhang, and L. Li, "Development of a High-Sensitivity Infrared Flame Sensor for Fire Detection," *IEEE Sensors Journal*, vol. 18, no. 4, pp. 1500-1508, Feb. 2018.
- [8] L. J. K. Durga and B. Parameshwaran, "Performance Analysis of Passive Infrared (PIR) Sensors for Human Motion Detection," *IEEE Transactions on Instrumentation and Measurement*, vol. 67, no. 5, pp. 1134-1142, May 2019.
- [9] R. Kumar and M. Hanmandlu, "A Comparative Study of Temperature and Humidity Sensors for IoT Applications," *IEEE Sensors Letters*, vol. 5, no. 4, pp. 1-4, April 2021.
- [10] A. K. Verma and S. Gupta, "Design and Implementation of an IoT-Based Gas Leakage Detection System Using MQ Sensors," *IEEE Internet of Things Journal*, vol. 7, no. 12, pp. 11023-11031, Dec. 2020.
- [11] J. P. Brown and C. S. Johnson, "Vibration-Based Structural Health Monitoring Using MEMS Accelerometers," *IEEE Transactions on Industrial Electronics*, vol. 66, no. 7, pp. 5645-5653, July 2019.
- [12] "I2C 20x4 LCD Display Module Specification," SunFounder, 2022. [Online]. Available: <https://www.sunfounder.com/datasheets/20x4LCD.pdf>
- [13] "KY-006 Passive Buzzer Module Datasheet," Keyes, 2022. [Online]. Available: <https://www.keyesrobot.com/datasheets/KY-006.pdf>