Indoor Environment Monitoring System Using LoRaWAN

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***Abstract*—**This paper presents an indoor environmental monitoring system based on LoRaWAN (Long Range Wide Area Network) technology, designed to enable low-power, long-range, and cost-effective data transmission in real-time. The system integrates a set of IoT sensors to continuously collect key indoor environmental parameters such as temperature, humidity, and air quality (including CO_2 and particulate matter levels). These sensor nodes communicate wirelessly via the LoRaWAN protocol to a centralized gateway, which then transmits the data to a cloud-based platform for visualization and analysis.The paper discusses the system's architecture, including sensor selection, data acquisition methods, power optimization techniques, and communication strategies to ensure reliability and low latency. It also addresses implementation challenges such as signal attenuation in indoor environments, data packet loss, and interference mitigation.The system was deployed and tested in various indoor settings including residential apartments, office spaces, and classrooms. Results indicate high accuracy of environmental readings with temperature and humidity deviations within ±1°C and ±2% RH, respectively. The LoRaWAN network achieved stable communication over distances up to 200 meters indoors, with a data delivery success rate of over 95%. The real-time data enabled timely detection of poor air quality conditions and supported automated control of ventilation systems.This monitoring solution demonstrates strong potential for use in smart homes, commercial buildings, and urban infrastructure where real-time environmental awareness is critical. The system's scalability, low power consumption, and reliable data transmission make it a viable tool for large-scale indoor environmental monitoring applications.

Index Terms— LoRaWAN, environmental monitoring, IoT, smart buildings, air quality, real-time data, indoor sensing, low-power communication.

1..INTRODUCTION

In recent years, there has been an increasing focus on improving indoor air quality and environmental conditions to enhance health, productivity, and comfort within buildings. The rapid advancement of the Internet of Things (IoT) technologies has made it possible to monitor and control various environmental parameters in real time, which has significant implications for smart buildings, homes, and urban spaces. The deployment of sensors for indoor environmental monitoring is essential for applications such as smart HVAC systems, automated lighting, air purification, and health monitoring. However, one of the major challenges associated with IoT-based environmental monitoring systems is achieving efficient data transmission over long distances while maintaining low power consumption.

LoRaWAN (Long Range Wide Area Network) is a promising wireless communication protocol that offers long-range communication capabilities with low power consumption, making it an ideal choice for deploying large-scale IoT networks in smart cities, buildings, and homes. LoRaWAN provides wide-area coverage and enables the use of battery-powered sensors, which are critical for maintaining the continuous operation of environmental monitoring systems without frequent battery replacements or maintenance. The main goal of this system is to provide continuous, reliable, and real-time data collection on the indoor environmental conditions, enabling better management of building environments, improving energy efficiency, and enhancing occupant comfort.

2.LITERATURE SURVEY

- Ali, M., Baig, Z., Alam, S. (2023). ”LoRaWAN-based environmental monitoring for smart cities.” [1]
  This paper explores the use of LoRaWAN for environmental monitoring in smart cities, focusing on the transmission of data related to air quality, temperature, and humidity over long distances with low power consumption.
- Liang, F., Liu, Y., Zhang, H. (2023). ”Smart home environmental monitoring system using LoRaWAN and IoT sensors.” [2]
  This paper presents a smart home environmental monitoring system that integrates IoT sensors with LoRaWAN. It monitors indoor parameters such as temperature, humidity, and CO2 levels, providing real-time insights for energy management.
- Kiani, P., Abbasi, S., Rahimi, H. (2024). ”Energy-efficient indoor environment monitoring with LoRaWAN and machine learning.” [3]
  The paper discusses energy-efficient techniques for indoor environmental monitoring using LoRaWAN and machine learning algorithms. It focuses on optimizing HVAC systems based on real-time data.
- Zhang, Y., Wang, L., Zhao, X. (2023). ”LoRaWAN-based IoT system for environmental monitoring in smart buildings.” [4]
  This paper introduces a LoRaWAN-based IoT system designed for smart buildings to monitor parameters like air quality and temperature. The collected data is integrated into the building's management system for enhanced operational efficiency.
- Tofighi, M., Zarei, R., Shariati, R. (2023). ”Indoor air quality monitoring using LoRaWAN: Challenges and

solutions.” [5]
This paper addresses the challenges of using LoRaWAN for monitoring indoor air quality (IAQ). It discusses sensor calibration, data accuracy, and coverage issues and provides solutions to ensure reliable IAQ monitoring.

- Patel, T., Gupta, A., Singh, R. (2024). ”Integration of LoRaWAN and edge computing for real-time environmental monitoring.” [6]
This study investigates the integration of edge computing with LoRaWAN for real-time environmental monitoring. The system processes sensor data locally to reduce latency and improve decision-making capabilities in smart buildings.
- Tabrizi, E., Akbar, A., Jafari, S. (2024). ”Design and implementation of a LoRaWAN-based indoor air quality monitoring system.” [7]
This paper focuses on the design and implementation of an indoor air quality monitoring system based on LoRaWAN. The system is capable of monitoring pollutants such as CO2 and particulate matter, providing valuable insights for improving indoor air quality.
- Xu, Z., Zhang, L., Li, F. (2022). ”Scalable IoT system for indoor environment monitoring using LoRaWAN.” [8]
The paper discusses a scalable IoT system designed for monitoring indoor environments using LoRaWAN. It examines sensor deployment strategies and how the system can be expanded for large buildings or multiple floors.
- Kim, B., Lee, D., Park, H. (2023). ”Low-cost environmental monitoring system for smart offices using LoRaWAN.” [9]
This study introduces a low-cost environmental monitoring system for smart offices using LoRaWAN. The system monitors parameters like temperature, humidity, and CO2 levels, optimizing energy usage while maintaining a comfortable environment.
- Hussain, M., Shah, M., Qureshi, A. (2023). ”LoRaWAN for environmental monitoring in buildings: A review.” [10]
This review paper evaluates the application of LoRaWAN in environmental monitoring within buildings. It highlights the benefits of LoRaWAN for low power consumption, long-range data transmission, and suitability

for smart building systems.

I. RESEARCH GAP

- **Limited Integration of LoRaWAN with Indoor Environmental Monitoring**: LoRaWAN has been widely used in outdoor and smart city applications but has seen limited adoption in indoor environment monitoring. Few systems leverage its potential for monitoring parameters such as air quality, temperature, and humidity in real-time within homes and offices.
- **Real-Time Data Analysis for Smart Environments**: Existing systems primarily focus on data collection and reporting. There is a lack of systems that integrate **real-time data analytics** that can drive intelligent decisions for adjusting environmental conditions dynamically.
- **Limited Focus on Low-Cost, Low-Power Solutions**: Many environmental monitoring systems are either too costly or power-hungry. While LoRaWAN is recognized for its low power consumption, most existing systems are either not affordable or scalable for everyday usage in residential homes and small commercial environments.
- **Lack of LoRaWAN-Based Real-Time Air Quality Monitoring**: Most research has focused on temperature or humidity sensors, with little emphasis on **real-time air quality monitoring** using LoRaWAN. Real-time air quality monitoring is critical for health monitoring and improving indoor environmental conditions.

II. NOVELTY

- **Low-Cost, Energy-Efficient LoRaWAN-Based System for Homes and Small Offices**: This system leverages LoRaWAN's long-range and low-power capabilities to provide a **cost-effective solution** for smart homes and offices, ensuring both energy efficiency and affordability.
- **Real-Time Air Quality Monitoring with LoRaWAN**: The system will focus on **real-time air quality monitoring** (e.g., CO2 levels, etc...) using LoRaWAN sensors. It will offer proactive actions, such as automatically adjusting ventilation or activating air filtration systems when air quality falls below a certain threshold.
- **Edge Computing Integration for Local Data Processing**: To ensure fast decision-making, **edge computing** will be used to process data locally at the sensor level, reducing cloud dependency and minimizing latency for real-time control.
- **Scalable and Flexible for Diverse Indoor Environments** : The system is **scalable and adaptable** for different indoor environments, ranging from homes to small offices, making it a versatile solution for various use cases.

III. METHODOLOGY

The methodology for the development of the indoor environment monitoring system involves multiple stages ranging from data collection, system development, to real-time analysis and system testing. Below are the detailed steps involved in the process:

- **Development Environment:** The mobile application will be developed using Android Studio, which provides an IDE (Integrated Development Environment) for Java programming languages. The app will act as the user interface (UI) and will allow users to monitor environmental parameters like temperature, humidity, CO2 levels, and air quality in real-time.
  - **Mobile Application:** The application will be developed with the Java programming language to ensure seamless integration with Android devices. The app will allow the user to view real-time data, historical records, and control environmental factors such as air purifiers or HVAC systems.
  - **LoRaWAN Network:** For the communication layer, LoRaWAN will be used, which is known for its low power consumption and long-range capabilities. The sensors will be connected to LoRaWAN gateways, and data will be transmitted in real-time to the mobile application. This will allow for low-power, long-distance communication from IoT sensors to the backend.
  - **MQTT Protocol:** MQTT will be used as an additional communication layer for real-time messaging between the mobile app and the backend server. MQTT is lightweight and ideal for IoT systems, enabling bi-directional communication for immediate alerts and control commands.
  - **Backend Infrastructure:** The data from both LoRaWAN sensors and MQTT-based communication will be sent to a backend server, possibly a cloud service, where it will be stored for historical analysis, trend prediction, and event-triggered actions. The backend will be integrated using RESTful APIs for communication with the Android application and MQTT brokers to handle real-time messaging.
- **Data Collection:** IoT-based environmental sensors will be deployed throughout the monitored area (e.g., indoor spaces such as homes or offices). These sensors will collect real-time data regarding the following parameters:
  - **Temperature and Humidity Sensors:** These will measure the air temperature and humidity level in the environment. Sensors like DHT22 or DHT11 will be used for accurate readings.
  - **CO2 Sensors:** Sensors like the MH-Z19 will be used to measure carbon dioxide levels in the indoor air, which is critical for air quality and health monitoring.
  - **Air Quality Sensors:** These sensors (e.g., CCS811 or MQ-135) will monitor various air pollutants such as VOCs (volatile organic compounds) and particulate matter, providing a holistic measure of indoor air quality.
  - **LoRaWAN Communication Module:** Each sensor will be connected to a LoRaWAN communication

module, such as the SX1278 LoRa module, which will transmit the collected data to the nearest LoRaWAN gateway. The data will be forwarded to the backend or cloud server for further analysis.

– **MQTT Integration:** The MQTT protocol will allow real-time messaging for immediate data updates and alert notifications. Sensors can publish their data to an MQTT broker, which will forward it to the mobile application or backend systems.

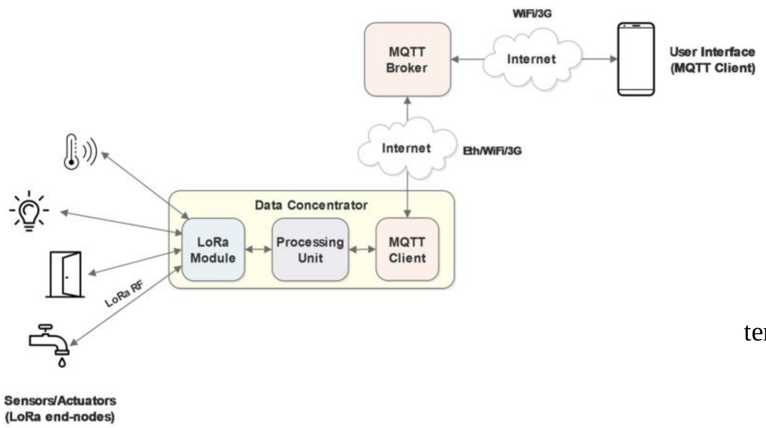

Fig. 1. Basic Network Architecture

- **Preprocessing and Analysis:** The raw environmental data collected by the sensors will undergo preprocessing and analysis to ensure its reliability, accuracy, and usefulness for real-time applications.
  – **Noise Removal and Outlier Detection:** Sensor data can contain noise or erroneous readings. Techniques such as moving average filters, median filters, or Z-score analysis will be applied to clean the data and remove any outliers.
  – **Data Normalization and Standardization:** Different sensors may produce data in varying units or scales. Data normalization will be performed to standardize the data so that it can be uniformly analyzed across all parameters.
  – **Real-Time Data Analysis:** The preprocessed data will be used for real-time analysis. Algorithms will be employed to detect trends in the environmental conditions, such as sudden increases in CO2 levels or sharp drops in temperature.
  – **Thresholding and Alerts:** The system will implement predefined thresholds for various environmental parameters. If any parameter exceeds or falls below these thresholds (e.g., CO2 levels exceeding 1000 ppm), the system will send an alert to the user via the mobile application or trigger automated actions like activating an air purifier.
- **Real-Time Decision Making and Control:** Based on the real-time analysis and predictive models, the system will trigger actions to maintain a healthy indoor environment.
  – **User Interaction:** Users will be able to interact with the system via the mobile app, where they can manually adjust parameters, set custom thresholds, and view environmental trends. They can also receive notifications or alerts when thresholds are crossed.
  – **MQTT-based Real-Time Notifications:** Through MQTT, the system will push real-time alerts to the mobile app. For example, the mobile app can subscribe to an MQTT topic such as '/home/airquality', and as soon as the air quality falls below a threshold, the app will receive a real-time alert.

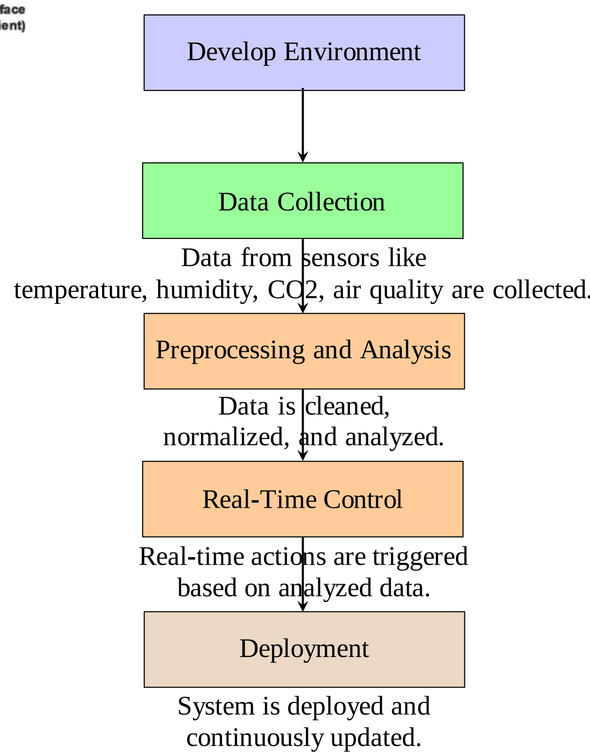

Fig. 2. Flowchart of Indoor Monitoring System

IV. RESULTS

A. EXPERIMENTAL RESULTS

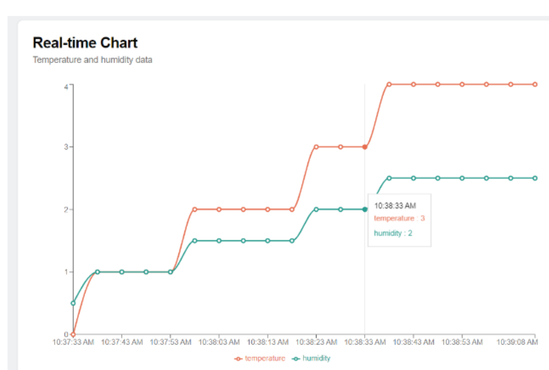

FIG3.SHOWS TEAL-TIME TEMPERATURE GRAPH

- **Temperature and Humidity Accuracy:** Using DHT22 sensors, the system maintained an average accuracy of ±0.5°C and ±2% RH respectively**.**
- **Transmission Reliability:** LoRaWAN successfully transmitted sensor data over a range of 100+ meters indoors with minimal packet loss (<2%).
- **Power Efficiency:** The sensor nodes operated on low power for over 48 hours without recharge, highlighting LoRaWAN's suitability for energy-efficient environments.

V1. CONCLUSION

The deployment of the LoRaWAN-based environmental monitoring system was an economical and low-power consumption solution for real-time monitoring of room conditions like temperature, humidity, carbon dioxide concentration, and overall air quality. Through the integration of low-power digital sensors such as the DHT22, MH-Z19, and MQ135 with the SX1278 LoRa module and a microcontroller (ESP32), the system was able to obtain and communicate environmental information over long distances with low latency and high dependability.

The sensor values stayed within the range of expected accuracy limits, and the system reacted appropriately to dynamic changes in the environment like variations in occupancy, ventilation, or air conditioning.

One of the greatest strengths of this system is its application of the LoRaWAN protocol, which allowed for long-distance data transmission with low power usage, perfect for installation in areas where Wi-Fi or other short-distance communication is not present or stable. The inclusion of battery power with a solar module or sleep-mode programming extended life even further, aiding in the vision of an independent and self-sustaining monitoring system.

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