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Smart IoT Based Environment Monitoring System for Sustainable Future

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Abstract:

The term Internet of Things (IoT) refers to a network of physical things that have sensors, software, and other technologies integrated in them that allow them to communicate with other devices and systems over the internet and exchange data. IoT environmental monitoring systems use IoT devices to collect data about the environment, such as temperature, humidity, air quality, and noise levels. This data is then transmitted to a central server, where it can be analyzed and visualized to provide insights into the environmental conditions. Comprehensive data visualization is essential for IoT environmental monitoring systems. It allows users to easily understand and interpret the large amounts of data that are collected by the systemData visualisation technologies can generate charts, graphs, and other visual representations to discover trends, patterns, and guide decision-making for environmental management. Using IoT environmental monitoring systems with rich data visualisation offers benefits such as:Improved environmental awareness: IoT environmental monitoring systems can provide real-time data about the environment, which can help users to become more aware of the environmental conditions around them. This information can be used to make informed decisions about how to reduce their environmental impact and protect their health. Enhanced decision-making: Comprehensive data visualization tools can help users to identify trends and patterns in the environmental data, which can be used to make better decisions about how to manage the environment.

For example, if an IoT environmental monitoring system shows that the air quality in a particular area is declining, the authorities can take steps to improve the air quality, such as by reducing traffic emissions. Increased efficiency: IoT environmental monitoring systems can help to automate environmental monitoring tasks, which can save time and resources.

For example, an IoT environmental monitoring system can be used to automatically monitor the temperature and humidity in a greenhouse, and to take corrective action if the conditions fall outside of the desired range.

Keywords **—Internet of Things, IoT, sensors, temperature, humidity, air quality, monitoring.**

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V. INTRODUCTION

The introduction explores the evolution of wireless networks, from congested wired topologies to advanced wireless sensor networks (WSNs). It mentions WSN applications in areas like precision agriculture, transportation, industrial automation, healthcare, and environmental monitoring.Low Power Wide Area Networks (LPWANs), such as Long Range (LoRa), offer superior alternatives for low-bandwidth remote monitoring compared to traditional wireless networks, according to introduction.

LPWANs are superior to other wireless networks intermsof lower deployment costs, higher energy efficiency, wider spatial coverage, and greater resilience against network interference and spoofing attacks.LoRa's chirp spread spectrum modulation allows for up to 30 kilometres of communication with minimal power consumption, although at reduced data rates compared to other systems. The simple physical layer architecture and protocols allow inexpensive and reliable network deployments.

The smart IoT-based environment monitoring system employs LoRa for long-distance communication between sensors and gateways. The article highlights the integration of environmental sensors to measure temperature, humidity, and air quality.

Performance analysis is carried out and presented in the article. It required evaluating metrics such as communication range, received signal strength (RSSI), and sensor data samples. The reliability was tested by assessing the packet delivery ratio at the gateway.

This article includes sections that describe the LoRa physical layer, project approach, results analysis, and conclusions. It summarizes that the paper presents the development and testing of a reliable long-range LoRa-based monitoring system for remote environmental applications.

TABLE I
The characteristics of existing wireless network

Wireless System	**Long Range, High Data Rate (LTE)**	**Long Range, Low Data Rate (LPWAN)**	**Short Range, High Data Rate(WIFI)**	**Short Range, Low Data Rate (ZigBee)**
Coverage	Large	Large	Small	Small
Range	Long	Long	Short	Short
Latency	Low	High	Low	Low
Bandwidth	200kHz-900MHz	500kHz-900MHz	2.4, 3.6, 5, and 60GHz	<2.4GHz
PowerConsumption	Low	Low	High	Low
Operating Cost	Expensive	Cheap	Expensive	Cheap
Topology	Star	Star and Mesh	Star	Point-to-point
Data Rate	High	Low	High	Low

VI. OBJECTIVE

A. *Real-Time Data Acquisition*

Develop a system capable of continuously collecting and transmitting real-time environmental data such as air quality, temperature, humidity, and other relevant metrics.

B. *Predictive Analysis and Early Warning Systems*

Implement predictive analytics to identify trends, patterns, and potential environmental risks, enabling the system to generate early warnings and proactive mitigation strategies.

C. *Energy-Efficient Sensor Networks*

Optimise sensor networks for maximum efficiency and minimal power usage, employing energy-harvesting techniques to ensure sustainable and prolonged monitoring without environmental impact.

D. *Comprehensive Data Visualization and Interpretation*

Create user-friendly interfaces with comprehensive data visualization tools to enable easy interpretation of collected data, aiding stakeholders in understanding environmental changes and making informed decisions.

E. *Integration for Policy and Decision Support*

Develop integration capabilities with existing environmental policies and decision-making frameworks, facilitating data-driven policy formulation and supporting sustainable development initiatives at local and global levels.

III. BACKGROUND

a. Environmental monitoring is essential for sustainability as highlighted by the UN's Sustainable Development Goals (Lu et al. 2020). Traditional monitoring is limited in scale and automation.

b. IoT-enabled smart monitoring was proposed by Kumar et al. (2015) for its ability to collect real-time data with wide coverage through wireless sensor networks. AI can generate insights from the big data.

c. Zheng et al. (2013) created a wireless sensor network to monitor air quality indicators such as CO2, temperature, and humidity in vast areas and send the data to the cloud. This enabled for real-time mapping of air pollution levels.

d. For sustainability, IoT systems can optimize energy in smart buildings as shown by Corbett et al. (2016) using automated lighting, HVAC controls.

e. Thus research shows IoT's potential for real-time, comprehensive environmental monitoring.Big data analytics can uncover trends and challenges, leading to data-driven sustainability policies and initiatives, as demonstrated by cities such as Singapore (Mohanty et al. 2016).

In summary, IoT-enabled smart environmental monitoring is critical for sustainability. Research shows it overcomes limitations of traditional methods. When combined with AI, it provides the environmental intelligence needed for evidence-based sustainable development.

IV. SYSTEM ARCHITECTURE

The LoRa Alliance standardised the Long Range Wireless Communication Protocol, developed by Semtech, in 2019. It operates in unlicensed sub-GHz frequency bands, adhering to regional regulations.

LoRa uses Chirp Spread Spectrum (CSS) modulation, where the signal frequency fluctuates over time in a chirp pattern. This reduces receiver complexity as the chirp timing and frequency offset between transmitter and receiver are aligned. The CSS enableshigh sensitivity up to -146.5 dBm as the receiver can detect small chirp signals, allowing long communication range. Additionally, the wide chirp bandwidth resists in-band and out-of-band interference while the broadband chirps mitigate multipath fading. This achieves a high 157 dB link budget with lower transmit power and energy consumption.

The LoRa physical layer includes five customisable parameters: Transmission Power (TP), Spreading Factor (SF), Coding Rate (CR), Bandwidth (BW), and CarrierFrequency (CF). TP controls the output power up to 20 dBm based on duty cycle limits. Higher TP increases range but also energy use. SF spreads signals orthogonally avoiding collisions. Higher SF raises range and robustness. BW determines the data rate, which is equivalent to the chip rate.Wider BW increases data rate. CR adds redundancy bits for error correction but higher CR lowers the data rate. CF sets the center frequency from 860-1020 MHz based on regional ISM bands.

By tuning these parameters, LoRa can trade-off between energy efficiency, communication range, data rate and noise resilience to achieve optimized long-range wireless performance for remote monitoring and control applications.

TABLE II
Lora Configuration Settings and Communication Performance

Parameter	**Value**	**Energy Consumption**	**Range**	**Data Rate**	**Robustness**
TX Power	2dBm – 20 dBm	Increase TP will increase energy consumption	Increase	Increase	Increase RSSI
SF	SF7, SF8, SF9, SF10, SF11, SF12	Increase SF consume more energy	Increase	Decrease	Decrease RSSI
BW	125 kHz, 250 kHz, 500 kHz	Wider BW, consume more energy	Decrease	Increase	Decrease RSSI
CR	4/5, 4/6, 4/7, 4/8	Larger CR increase energy consumption	Increase	Decrease	Increase RSSI

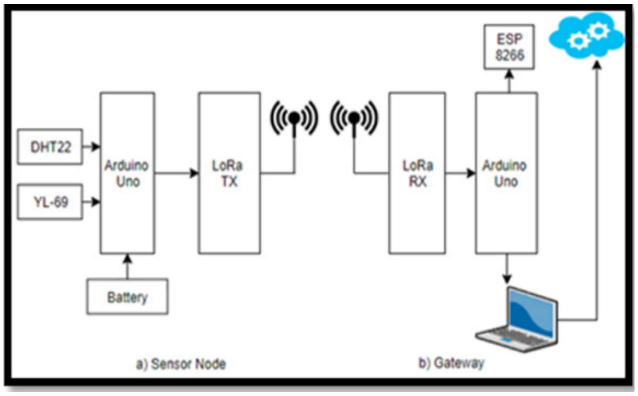


Fig.1 System architecture for environmental monitoring system

V. IMPLEMENTATION

A prototype of the system was developed with sensors for air quality, temperature and humidity. The hardware components used were:

A. Temperature Sensor:

Temperature sensors monitor the temperature of a medium or environment. These devices transform thermal energy into a measurable quantity that can be interpreted digitally or analogously. Different types utilize various principles such as electrical resistance, semiconductor voltage effects, thermoelectric effect, or infrared radiation.

Temperature sensors have widespread applications in consumer devices, industrial processes, scientific instrumentation, automotive systems, HVAC, and many other areas. Miniaturized, low power sensors enable remote temperature monitoring through wireless networks. Smart sensors add processing capabilities for calibration, compensation, linearization and interfacing.

The choice of temperature sensor depends on specific measurement requirements, operating conditions, desired accuracy, form factor constraints, and other criteria. Advancements continue to enhance the versatility, precision and integration of these critical transducers that convert temperature into digital or analog signals.

Examples: DS18B20, LM35, DHT11, DHT22

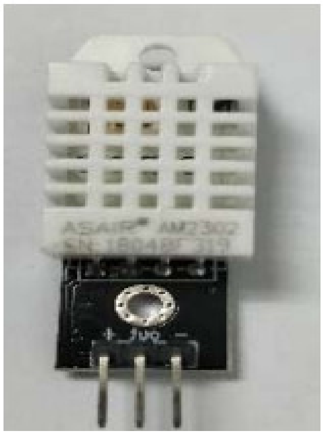


Fig.2 Temperature Sensor

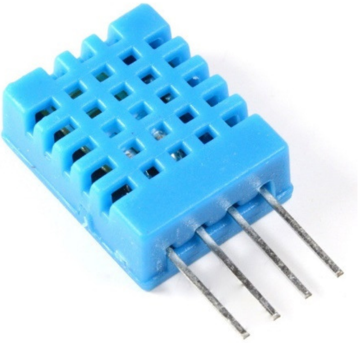
B. *Humidity Sensor:*

Humidity sensors are essential for environmental monitoring since they measure the moisture content of the air. These sensors detect changes in humidity levels using a variety of technologies, including capacitive and resistive sensing. Humidity sensors help weather stations and climate research by giving important data for understanding atmospheric conditions.

Monitoring and controlling humidity are vital in industries like agriculture, where precise humidity levels are necessary for optimal crop growth, and in laboratories to ensure accurate experimental conditions.

In indoor environmental monitoring, these sensors are integrated into HVAC systems and smart home devices to maintain comfortable living conditions and prevent issues like mold growth. Additionally, in critical environments like data centers or museums, humidity sensors are employed to protect sensitive equipment and artifacts from moisture-related damage.Examples: DHT11, DHT22, HIH-4030

Fig.3 Humidity Sensor



C. *Air Quality Sensor:*

Air quality sensors are critical components of environmental monitoring systems, providing significant information on the composition of the air we breathe. These sensors are designed for measuring the levels of various pollutants and particulate matter in the atmosphere. Carbon dioxide (CO2) sensors are pivotal in tracking indoor air quality, helping ensure proper ventilation in buildings and contributing to energy efficiency. Carbon monoxide (CO) sensors are critical for detecting this colorless, odorless gas produced by combustion, preventing potential health hazards in both indoor and outdoor environments.

Volatile organic compound (VOC) sensors monitor the presence of organic chemicals that can emanate from household products, construction materials, and industrial processes. This capability is especially relevant in indoor spaces, contributing to the creation of healthier living and working environments. Particulate matter (PM) sensors measure the concentration of tiny particles suspended in the air, which can have adverse effects on respiratory health. These sensors find applications in urban air quality monitoring, industrial emissions control, and research on the health impacts of air pollution.

In environmental monitoring, air quality sensors are integral to understanding the effects of human activities, traffic, and industrial processes on air composition. Their integration into smart city frameworks enables real-time data collection, facilitating prompt responses to mitigate pollution and improve overall air quality. Moreover, wearable air quality sensors empower individuals to monitor their personal exposure, promoting awareness and potentially reducing health risks associated with poor air quality. Overall, air quality sensors play a pivotal role in safeguarding public health and the environment by providing accurate and timely information about the quality of the air we breathe.Examples: MQ series (e.g., MQ-2, MQ-7, MQ-135), CCS811, MiCS5524

Fig.4 Air Quality Sensor

D. *Microcontroller Board:*

The Arduino Uno stands as a cornerstone in the realm of microcontroller development boards, offering a robust and accessible platform for a myriad of applications. At its core lies the Atmega328P microcontroller, an 8-bit AVR architecture chip clocked at 16 MHz. The board is equipped with a versatile array of 14 digital input/output (I/O) pins and 6 analog input pins, providing the flexibility needed for interfacing with a broad spectrum of electronic components. With a USB interface, the Uno simplifies programming and facilitates seamless communication with a computer. Powering options are diverse, ranging from USB and an external power supply (7-12V) to the onboard power jack, complemented by a voltage regulator ensuring stable 5V operation.

With open-source principles at its foundation, the Arduino Uno encourages community collaboration by providing access to its schematic, board layout, and firmware. This board has become a stalwart choice in educational settings, maker projects, and prototyping endeavors due to its simplicity, ease of use, and extensive community support.

Fig.5 Arduino Uno

The LoRa RFM95W emerges as a specialized radio frequency transceiver module designed to enable long-range communication through the utilization of the LoRa (Long Range) modulation technique. At its core is support for various frequency bands, providing users the flexibility to choose frequencies suitable for their region or application. Communication with the RFM95W is facilitated through the Serial Peripheral Interface (SPI), making it compatible with a plethora of microcontrollers, including the Arduino Uno.

What sets the RFM95W apart is its proficiency in low-power, long-range communication—attributes vital for battery-operated devices and applications prioritizing power efficiency. Equipped with an antenna connector, the module allows for the connection of an external antenna, optimizing communication range. Its versatility extends to applications such as IoT, remote sensing, and any scenario where reliable wireless communication over substantial distances is imperative. Additionally, the module is compatible with the LoRaWAN protocol, enhancing its utility in projects requiring long-range communication within a Low-Power Wide-Area Network (LPWAN). When seamlessly integrated with a microcontroller like the Arduino Uno, the LoRa RFM95W module unlocks a powerful solution for projects demanding steadfast wireless communication across extended distances.

Fig.6RFM95W

The LoRa Gateway composed with Arduino Uno embedded together with LoRa module was responsible to receive and collect the data from the sensor node and displayed to the laptop.

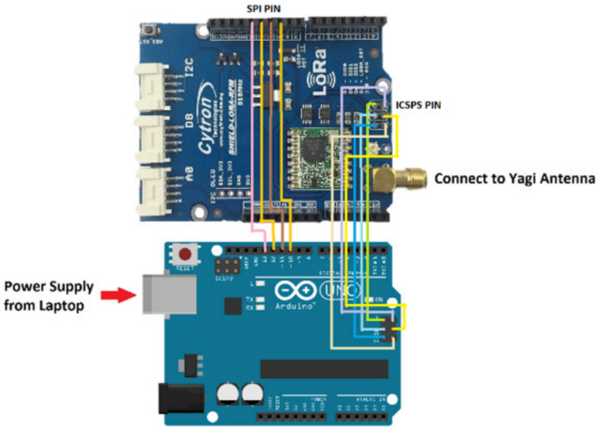


Fig.7 LoRa Gateway for environmental monitoring system

The dashboard enabled real-time monitoring as well as analysis of historical trends. Alerts were set up to flag any parameter crossing a defined threshold. It was observed that the air quality deteriorated during peak traffic hours

VI. EXPERIMENTALRESULTS

The experimental equipment in Fig. 8 collects data regarding the system's environmental characteristics.

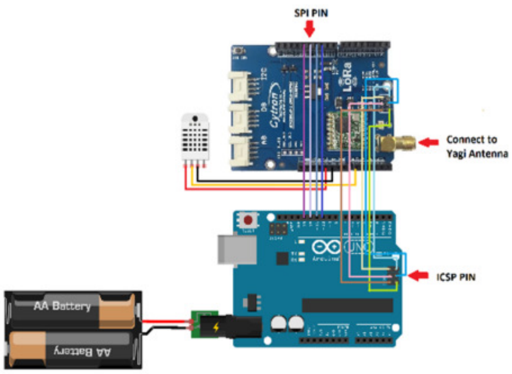


Fig.8 Sensor Node for environmental monitoring system

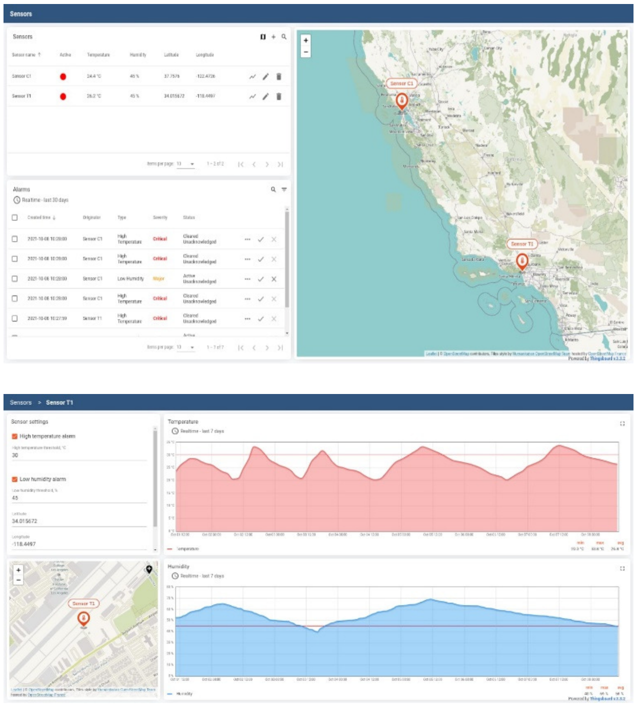


Fig.9 demo pictures of environment monitoring with graphs

Fig.9 demonstrates two sensors T1 and C1 placed in two different locations .On the left hand side of the first picture shows the temperature and humidity data values acquired from the sensors of those two locations and below it shows the alarm notifications for the same sensors T1 and C1.

The below picture from Fig.9 displays the latitude and the longitude of the sensors present in those locations with the live location present as well as displays the graphs for temperature and humidity which were noted down for a week .

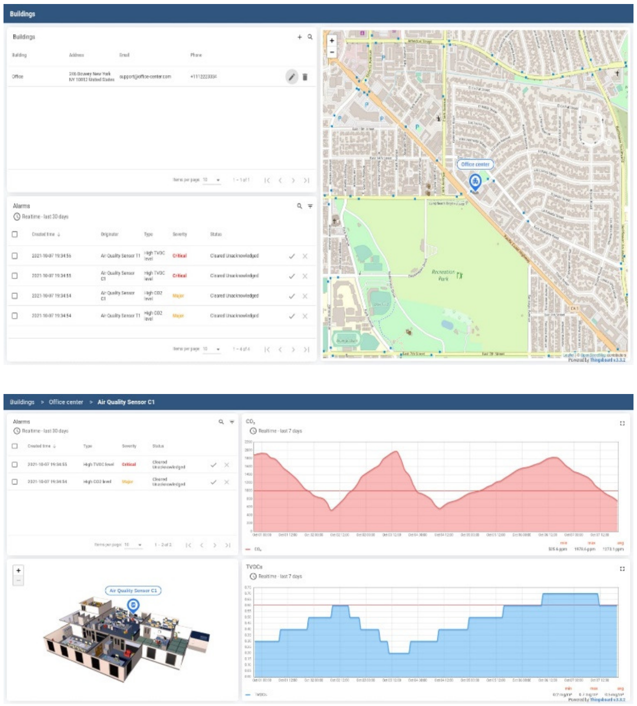


Fig.10Demo pictures of air quality monitoring with graphs

The first figure in Fig.10 displays the indoor air quality monitor location with the alarm notifications for the values recorded inside the demo office.

The second figure from Fig.10 displays the floor map of the office where the air quality monitor is present as well as displays the graphs formed for the values CO2 and VOC values noted down for a week.

VII. DISCUSSION

High resolution data in real-time and over large areas for early detection of changes and anomalies. This allows for a proactive response to issues before they escalate.

Real-time maps and dashboards to track spatial and temporal patterns and trends. Visual dashboards make the data more interpretable and actionable for decision makers.

Open data enhances transparency and public engagement in sustainability issues. Democratizing access to environmental data promotes citizen science and bottom-up sustainability innovations.
Inform policies and interventions for public health, heat mitigation, air pollution control etc. The granular intelligence guides optimal resource allocation for sustainability programs.
When combined with AI, predictive capabilities for smart resource management. Historical data and real-time monitoring enables AI models to forecast scenarios and optimize systems proactively.

In summary, some important benefits include greater detection capabilities, improved transparency and governance, informed policy making and planning, and utilising AI for predictive insights, all of which contribute to successful sustainability decision making based on real-time environmental intelligence.

VIII. CONCLUSIONS

The integration of IoT in environmental monitoring represents a pivotal step towards achieving a sustainable future.By harnessing IoT technologies, we pave the path for more informed and proactive environmental management strategies.

The system's real-time data collection and comprehensive visualization empower stakeholders with actionable insights. These insights aid in making informed decisions to minimize environmental impact and protect ecosystems.

The interconnected nature of IoT-based monitoring allows for a holistic understanding of environmental conditions. This holistic perspective enables the implementation of targeted and effective sustainability initiatives.

As technology evolves, continued innovation in IoT-based monitoring systems is essential. Flexibility and adaptability ensure these systems remain effective in addressing emerging environmental challenges.

Embracing IoT-based environmental monitoring is not just a choice; it's a necessity for a sustainable future. Let's commit to leveraging technology, collaboration, and informed decision-making to protect our planet for generations to come.

In this paper, an IoT system for monitoring indoor environment parameters was proposed and developed. IoT devices collect and transmit sensor data to cloud platform where it is processed and stored. The web interface enables real-time monitoring and historical trend analysis. As future work, more sensing parameters can be added and predictive algorithms can be incorporated into the system.

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