LoRaWAN based IoT Architecture for Environmental Monitoring in Museums

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ABSTRACT
Cultural heritage, particularly its tangible forms such as buildings, monuments, landscapes, archive materials, books, works of art, and artifacts, is essential for maintaining the cultural identity and history of societies. The preservation of these diverse forms of heritage is paramount. In recent years, technological advancements have opened new avenues for enhancing museum preservation efforts. The advent ofthe Internet of Things (IoT) has brought about innovative solutions for real-time environmental monitoring. Within this broader IoT landscape, the Internet of Cultural Things (IoCT) has emerged as a specialized framework that integrates IoT technologies into cultural heritage contexts. IoCT encompasses the application of IoT to enhance the preservation, management, and presentation of cultural heritage, making it particularly relevant to museum preservation efforts. This paper proposes a LoRaWAN-based IoT architecture designed for monitoring environmental conditions within museum premises, utilizing DHT11 and MQ135 gas sensors. The proposed system aims to address the limitations of existing technologies and provide a solution for museum environmental monitoring.

Keywords: Smart Museum, Preservation, Cultural heritage, Internet of Cultural Things (IoCT)

1. INTRODUCTION

Museums, custodians of our collective memory, serve as vital repositories of our cultural [2] and historical heritage. Their significance lies not only in housing artifacts but in preserving the essence of our past for future generations. However, behind their tranquil façade, museums face a silent struggle—the battle against time and environmental factors that threaten the integrity of their exhibits. Poor air quality inside museums is one of the main factors influencing the state of conservation of exhibits. Despite being placed in controlled environments due to their construction materials, exhibits can be very vulnerable to fluctuations in the internal microclimate. To address the above challenges, museum professionals rely on established standards and guidelines, such as the UNI10829:1999 standard [3] that offers comprehensive recommendations for maintaining optimal environmental conditions within museum spaces, crucial for the preservation of artifacts and cultural heritage. For instance, the standard advises maintaining specific temperature and humidity levels tailored to different types of collections illustrated down below in Table 1.

Table 1. Guidelines for Artifact Preservation in Museums based on UNI 10829:1999 standard

Ref	Artifact Type	Temperature (°C)	Relative Humidity (%)	Gas Levels
[3]	Paper And Books	13–18	50–60	Low levels of gas
[3]	Paintings onCanvas	19–24	40–55	Low levels of gas
[3]	Photographic films	0-15	30-45	Low levels of gas
[3]	Furniture, Sculptures &Paintings on Wood	19-24	50-60	Low levels of gas

[3]	Mosaics, Rocks, Stones	15-25	20-60	Low levels of gas
[3]	Metals, Armor,Silver	18–22	30–50	Low levels of gas
(°C) Celsius (%RH) a percentage Relative Humidity				

As illustrated by the guidelines outlined in Table 1, meticulous environmental control measures are important in safeguarding our cultural heritage from the detrimental effects of fluctuating temperature, humidity, and gas levels. However, as we navigate the ever-evolving landscape of museum preservation, the need for advanced solutions becomes increasingly apparent.

Furthermore, past incidents [4][5][6], serve as poignant reminders of the fragility of our cultural treasures. These incidents underscore the imperative for proactive measures and the importance of leveraging technology to mitigate risks. In light of such events, our exploration of innovative solutions becomes even more pressing.

2. LITERATURE REVIEW

The importance of adopting wireless sensor networks in museums to monitor microclimates effectively, ensuring stable conditions for exhibits and visitors. These advancements showcase the integration of cutting-edge technologies to safeguard cultural heritage artifacts and improve conservation practices in museum settings. Various technologies have been employed to address these needs, each with its own set of advantages and limitations. And Table 2 provides a comprehensive overview of various wireless technologies used for environmental monitoring in museums. Rioual [7] demonstrated that RFID sensors could effectively monitor specific environmental parameters such as corrosively, providing valuable data for museum conservators.

However, RFID technology typically offers short-range communication and requires a dense network of readers, leading to higher installation and maintenance costs. Gawade [8] proposed, the performance of a battery-less near field communication (NFC) sensor for museum artifact monitoring was evaluated using a commercial Tagformance measurement system, and the measured RF sensitivity and -3 dB bandwidth values were in close agreement with the ISO/IEC 15693 standard. Hinostroza [9] et.al in their research paper focuses on the design and implementation of a wireless sensor network using Bluetooth Low Energy and ZigBee technologies to monitor environmental conditions in spaces where cultural heritage objects are stored. The wireless sensor network is capable of measuring various parameters such as temperature, moisture, light intensity, irradiance, and particulate matter 2.5 and 10, providing crucial data for the preservation of cultural artifacts. Ma and Changsong et.al [10] designed and implemented of a museum cultural relic microenvironment monitoring system based on ZigBee wireless communication network technology ensuring low power consumption, convenient networking, strong scalability, and the ability to detect various environmental parameters for effective micro-environment monitoring of museum cultural relics showcases.

Ghada Alsuhly and Ahmed Khattab [11] showed that by integrating sensors, gateways, cloud storage, and actuators, the IoT system ensures continuous monitoring, analysis, and control of the museum ambience to maintain optimal conditions for artifact preservation. The system's architecture facilitates seamless data flow from sensors to cloud storage, enabling efficient decision-making processes based on real-time data analysis.

Firdhous [12], proposed a paper that showcases the implementation of IoT applications in various areas such as environment management, home monitoring, security systems, and more, demonstrating the versatility and potential impact of the proposed model. The IoT device in the proposed monitoring system is connected to the Internet and transfers data to the processing station using the 4G5G mobile communication network. Ji, Hang, [13] et.al proposal focuses on the design and development of an indoor environment monitoring system based on NB-IoT and sensor technology. The system collects indoor environment parameters in real-time using multiple sensor nodes, transmits the data via ZigBee to a gateway, and uploads it to a service center through NB-IoT. Perles[14] et.al emphasize in their study that by utilizing wireless technologies like LoRa and Sigfox in the ISM band, the proposed system can effectively monitor artworks in various scenarios, including museums, churches, and open-air archaeological sites, ensuring data collection even in challenging environments.

Despite the availability of technologies such as Wi-Fi, Zigbee, and Bluetooth, our analysis reveals inherent limitations in terms of range, power consumption, cost, and potential for interference. Among these options, LoRaWAN emerges as a promising choice for museum environmental monitoring. Because LoRaWAN supports long-range communication, allowing coverage of extensive museum areas with fewer devices. LoRaWAN devices consume minimal power, extending battery life and reducing the need for frequent maintenance. The low cost of LoRaWAN devices and infrastructure makes it an economical choice for museums of all sizes. LoRaWAN's architecture supports the addition of numerous sensors without significant increases in cost or complexity. In response to the limitations identified in the literature review, and capitalize on the strengths of LoRaWAN, our paper in Fig.1 proposes a LoRaWAN-based IoT architecture for environmental monitoring in museums. Our system utilizes DHT11 and MQ135 sensors to monitor temperature, humidity, and gas levels. These sensors are strategically placed throughout the museum connected to LoRa nodes, which transmit data to a LoRa gateway then the data sent to a web platform for real-time analysis and visualization. In the subsequent sections of this paper, we will delve into a detailed analysis of our proposed system, covering sensor deployment strategies, data transmission mechanisms, backend processing, and visualization interfaces. Through this exploration, we aim to demonstrate the efficacy and feasibility of our LoRaWAN-based solution in addressing the unique challenges faced by museums in preserving their invaluable artifacts.

Table 2. Comparison of Wireless Environmental Monitoring Technologies for Museums

Ref.& Year	**Wireless Technology**	**Network Topology**	**Transmission Range**	**Environment**	**Power consumption**	**Visualization**	**storage cloud**	**Data Accuracy**	**Maximum Floor coverage**	**Application**
[7], 2020	RFID	bus	Short	Indoor	Low	No	No	High	1 floor (Short range)	Environmental Monitorring
[8], 2021	NFC	P2P	Short	Indoor	Low	No	No	High	1 floor (Short range)	Environmental Monitorring
[9], 2022	Bluetooth Low Energy (BLE)	Mesh StarP2P	Short	Indoor	Low	No	No	High	1 floor (Short range)	Environmental Monitorring
[10], 2020	Zigbee	mesh	Medium	Indoor	Low	No	No	High	2 floors (Mediumrange)	Environmental Monitorring
[11], 2023	Wi-Fi	Star	Medium	Indoor /Outdoor	Medium	Yes	Yes	High	2floors (Long range)	Environmental Monitorring
[12] 2018	GPRS 4G/5G	Star	Long	Indoor /Outdoor	High	Yes	Yes	High	3-4 floors (Long range)	Environmental Monitorring
[13] 2018	NBIoT	Star	Long	Indoor /Outdoor	Low	Yes	Yes	High	5 floors (Long range)	Environmental Monitorring
[14] 2018	Sigfox	Star	Long	Indoor /Outdoor	Low	Yes	Yes	High	5 floors (Long range)	Environmental Monitorring
2024 Propo sed system	Lora wan	Star	Long	Indoor /Outdoor	Low	Yes	Yes	High	5 floors (Long range)	Environmental Monitorring

3. PROPOSED SYSTEM

The architecture of our IoT-MMS (Museum Monitoring System) that is illustrated in Fig. 1 is designed to provide comprehensive environmental monitoring, including collecting indoor environment parameters such as temperature, humidity, and air quality in real-time using multiple sensor nodes which are placed strategically throughout the museum to ensure that all areas are covered. The sensor nodes are connected to a LoRa node, which transmits the collected data to the LoRa gateway and analyzes and displays the data within the museum premises.

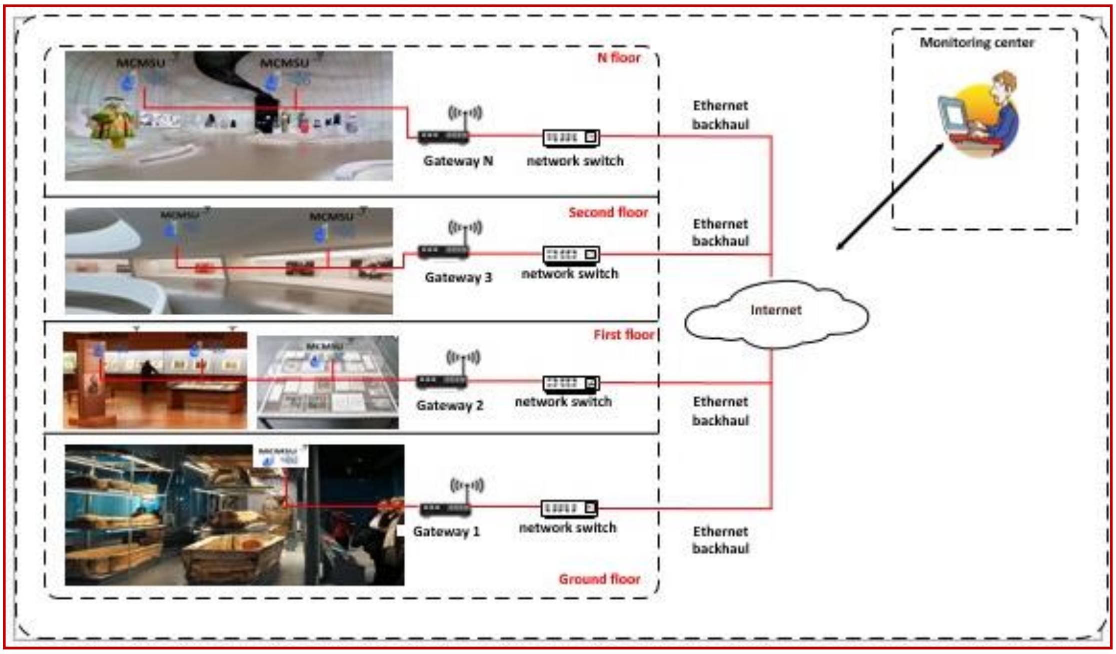

Fig 1. Network architecture of the proposed IoT-MMS

A MMS mainly comprises DHT11 sensor to measure the temperature and humidity level in the museum, MQ135 sensor to measure the gas level of the indoor museum, a host microcontroller to process the data, and a LoRa module for wireless transmission. The schematic diagram of the MMS is portrayed in Fig. 2, and the installation of the MMS in the museum is shown in Figs.

The DHT11 sensor is a cost-effective, high-performance sensor that operates at a voltage range of 3.3 to 5.5 V, with a typical current consumption of 2 mA. It can measure temperatures from 0 to 50°C with an accuracy of ±2°C, and humidity from 20 to 80% with an accuracy of ±5%. The MQ135 sensor detects a wide range of gases, ensuring that air quality is monitored effectively. These sensors are connected to the host microcontroller via pulse width output format for the DHT11 and analog voltage for the MQ135. LA66 module supports the LoRaWAN networking protocol, enabling reliable data transmission over extensive distances while maintaining low energy usage, which is crucial for continuous environmental monitoring in museum settings. By integrating the LA66 module with DHT11 and MQ135 sensors, we are able to effectively monitor temperature, humidity, and gas levels throughout the museum premises. The LA66 module's capabilities ensure that data collected by the sensors are transmitted seamlessly to the LoRa gateway, from where it is sent to a web platform for real-time analysis and visualization.

Fig 2. Various parts of the MMS

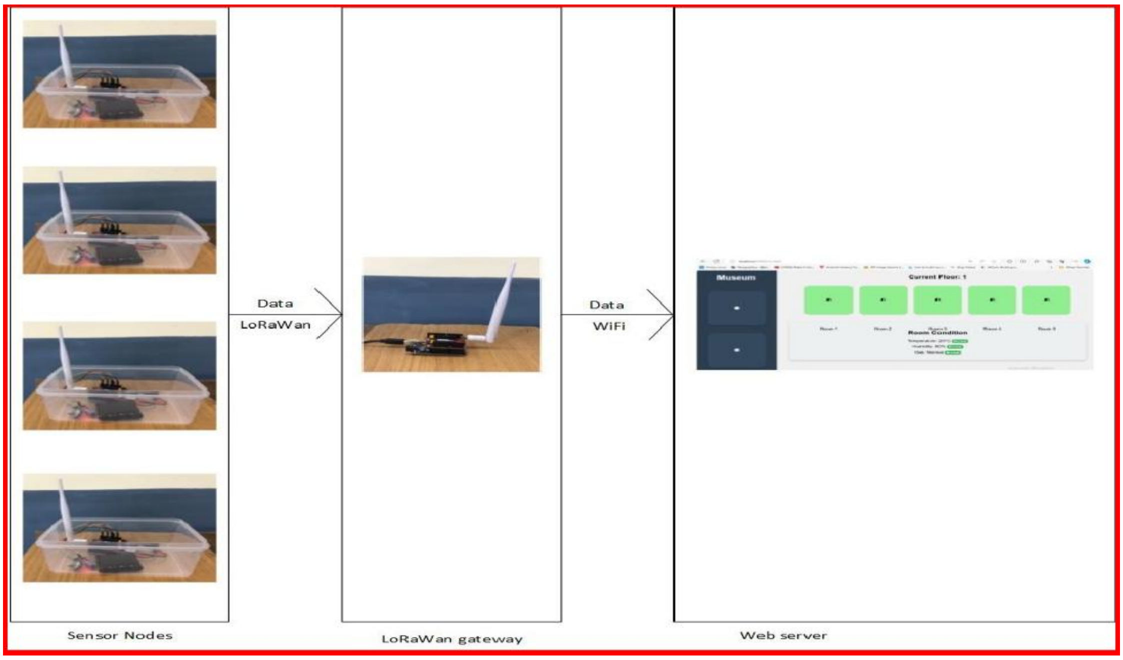

Fig 3. The architecture of the environmental sensing platform

In the architecture of MMS each sensor node which is illustrated in Fig 3 is equipped with DHT11 and MQ135 sensors to measure temperature, humidity, and gas levels. The collected data from these sensors is transmitted to a LoRa gateway via the LA66 LoRaWAN Module, which ensures reliable long-range communication with low power consumption. From the LoRa gateway, the data is then transmitted using Wi-Fi to a central server for storage and processing. The central server hosts advanced visualization interfaces and dashboards, enables the museum staff to monitor and take action on environmental parameters and air quality in real-time.

4. CONCLUSION

This paper presents the design and implementation of an innovative IoT architecture tailored specifically for monitoring environmental conditions within museum premises. By leveraging LoRaWAN technology in conjunction with DHT11 and MQ135 sensors, the system offers a comprehensive solution to the challenges of artifact preservation and museum management. The development of our proposed system involved careful consideration of various factors, including sensor deployment strategies, data transmission mechanisms, backend processing, and visualization interfaces. Through rigorous validation, we have demonstrated the efficacy and feasibility of our solution in accurately monitoring temperature, humidity, air quality, and other critical environmental parameters. Looking ahead, future research in this field could explore additional enhancements to further optimize the performance and functionality of our IoT architecture.

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