Wireless Sensor Network for Environmental Monitoring of Cultural Heritage

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Abstract: Cultural heritage assets represent the history and unique identity for every nation in the world, so their protection and conservation are mandatory tasks. However, although such assets are usually exhibited in special museum rooms, sometimes the environmental conditions may be modified, putting the materials at risk. These facts can be more severe in warehouses, where environmental conditions can vary even more. Most of the measurement sites are located in spaces that make it difficult or do not allow the handling of commercial devices for measuring multiple environmental parameters, either due to their size, energy consumption or because they cannot be connected to the internet, so there is no timely availability of information on the environmental condition in which they are found. This work presents the design and implementation of a wireless sensors network based on Bluetooth Low Energy and ZigBee, able to measure temperature, moisture, light intensity and irradiance, and particulate matter 2.5 and 10, in the different spaces where objects of cultural heritage are found. These measurements are sent to a web platform through the use of Wi-Fi or GPRS technology.

1 INTRODUCTION

Due to the great impact of environmental factors on the deterioration of materials, the monitoring of these factors is essential for making risk management decisions and for establishing preventive conservation strategies for heritage assets (Morales, 2000). Environmental data collection equipments can have two forms of storage, real and remote. While local storage (in the device itself) uses robust and consolidated technologies, viewing or downloading the collected information requires the presence of the people in charge and, in emergency cases (for example, during lockdowns) it is not possible to access information to take conservation decisions. Instead, remote storage devices allow data to be sent to a cloud, from which it can be accessed from anywhere in the world. This requires relatively new connectivity technologies since they depend on the physical and technological infrastructure of the place. In addition, they depends on the presence of networks that allow access to remote servers since they require Internet connectivity like Wi-Fi or Ethernet cable.

The collection of information on environmental parameters is essential for decision-making in preventive conservation. There are some limitations in this regard that includes: infrastructure that makes it difficult to install monitoring equipment with low autonomy or that requires electrical wiring since constant labor will be needed to be able to give it the respective maintenance; limited number of personnel trained in-situ to manage the information collected; the location of the assets to be monitored (both geographically and inside the building itself) as this can bring connectivity limitations; the huge diversity of the heritage that implies the need to use different sensors that allow measuring different environmental parameters corresponding to the most relevant for each type of material. All of these facts make it impossible for researchers to know the environmental conditions of the places where they save or conserve the heritage.

In the literature we can find some environmental monitoring systems developed for heritage conservation. In (Tse et al., 2018) the authors developed a remote particulate matter measurement system for the care of collections in museums and sensors send measured data directly to an AWS EC2 server over Wi-Fi. As we can see, they do not include more sensors in their system and since the sensors send data directly to server, the autonomy of the system is low. In (Alsuhly and Khattab, 2018; Tse et al., 2020) the authors present the design of a WSN with a complete sen-

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sors set including temperature, humidity, light, acceleration and presence by using IR sensor. In this system, a Raspberry Pi gateway establishes the connection among the nodes and the server through Wi-Fi. The results show that the lifetime is approximately 9.8 days with the use of three 600 mAh batteries since the use of a high-power system like Raspberry. The systems in (Shah and Mishra, 2016; Peralta et al., 2010) works with a local server where the data is saved continuously. This implementation difficult to achieve a timely conservation work. The works in (Al-Habal and Khattab, 2019; Eltresy et al., 2019; Zhang and Ye, 2011; Viani et al., 2014) shows the use of WSN by using IEEE 802.15.4 standard communication like ZigBee or ISM bands. These implementations were performed until a first stage of prototyping, so if these systems were used in real places for a long time, they would not work properly.

Therefore, the proposal of this work is based on the basic requirements that monitoring devices must have in the context of heritage conservation. These requirements include long autonomy for low maintenance; Wide set of sensors and remote data availability that do not depend on the physical and technological infrastructure of the place. Thus, this work presents the design and implementation of a wireless sensor network based on peripheral and central nodes. In addition, to improve usability, we proposed the development of modular hardware and an easy-to-use online platform.

This paper is divided as follows: in Section II we described some considerations that were made during the design process; in Section III we describe the methods and tools used to accomplish the objectives of this work; in Section IV is focus on the results and finally, we present the conclusions in Section V.

2 DESIGN CONSIDERATIONS

In order to develop the whole proposed system (hardware and software), in this Section we describe the considerations used to achieve the objectives of this work.

2.1 Long Autonomy

In order to achieve low maintenance on the hardware, it is necessary for it to remain operational for a long time depending on the sample rate of the environmental parameter measurements. Since the devices are battery powered, this consideration is the most important.

2.2 Wide Sensors Set

Given the huge diversity of the heritage, it implies the need to use different sensors that allow measuring different environmental parameters corresponding to the most relevant for each type of material. The most relevant environmental parameters are temperature, relative humidity, illuminance, irradiance and particulate matter. So the devices should be capable of measure all these parameters.

2.3 Remote Data Availability

This consideration implies the use of Internet connectivity. Due to the geography location and the infrastructure of the building where the heritage is found, the Internet connectivity must remain constant or at least, it must be available when data needs to be uploaded. Due to this consideration, it is important to the develop a system capable of guaranteeing the Internet connection in the devices.

3 METHODOLOGY

The project starts from the recognition of the needs of a group of museums and archaeological sites, from which the most relevant parameters are known according to the researchers or those responsible for maintaining a collection. Then, the required sensors are acquired and it is decided to build networks of environmental monitoring systems (nodes) capable of working with a specific type of connectivity. Each network has a central node and several peripheral nodes; the peripheral nodes send information to the central node through a local wireless network (BLE or ZigBee). The central node is responsible for sending it to a online platform using WiFi or GPRS. The nodes can include sensors for temperature, relative humidity, iluminance, irradiance and particulate matter. The hardware of the proposed system allows the coupling and decoupling of various sensors, as well as wireless communication modules, in such a way that the monitoring systems developed can be adapted to different needs and realities. We divided the methodology in hardware and software development and it is described following the schematic shown in Figure 1.

3.1 Hardware Development

In this section we will describe the design and implementation of the system's hardware. The hardware includes electrical, mechanical, electronics components, sensors ICs, wireless modules and batteries.

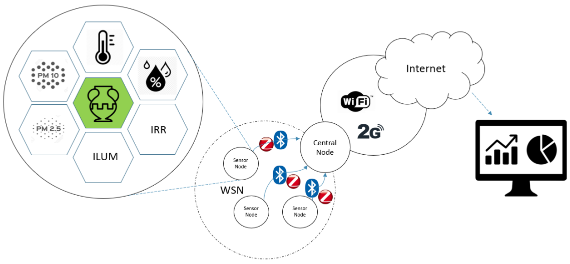

Figure 1: System Schematic Diagram.

The modular hardware proposed allows to have a single physical device with two functionalities within the wireless sensor network (WSN): central node and peripheral node. Also, if a device is used as a peripheral node, it may have one or more sensors included. It allows the user to have a versatile and more simplified device to use, since they can choose the components (sensors and wireless modules) that they want to have in a certain application. The use of Board-to-board (B2B) connectors were used in order to perform this feature in the hardware. The mainboard is where the sensors and wireless module can be coupled and decoupled from. It is mainly based on an ATmega1284P 8-bit microcontroller, a M24M01 EEPROM memory from ST, an external TPL5110 timer and a FTDI UART-to-USB bridge IC with micro-USB connector.

The table 1 presents the list of sensors and wireless modules used for this application. The sensors were chosen by considering low power consumption, reduced size and high accuracy. The wireless modules where chosen by considering the range, RF power and communication protocol. ZigBee was chosen as long range alternative for BLE, so it is used in places where a long range WSN is needed.

The devices are powered by 1600 mAh Li-Ion batteries in 2S1P configuration. Even though all devices have batteries, the devices meant to be used as central node need to be plugged into the wall due to the high consume they require. However, if the wall power fails, these devices will remain alive up to three hours.

3.2 Software Development

The system software consists of the online platform and the firmware that has been programmed on the microcontroller. The firmware is unique for all the twenty devices developed since, being modular hardware, it must contain the operating algorithm for both the central and peripheral nodes. Although, the firmware is different when using ZigBee or BLE due to the incompatible I/O pins.

The online platform was implemented by using Amazon Web Services (AWS) and the architecture diagram is presented in Figure 2. The platform was designed for HTTP connections with the devices over the Internet and the users can access by using a PC or mobile phones. The platform back-end is capable of storing data and allow many connections from users and devices. The platform front-end was designed by using HTML, CSS and JavaScript.

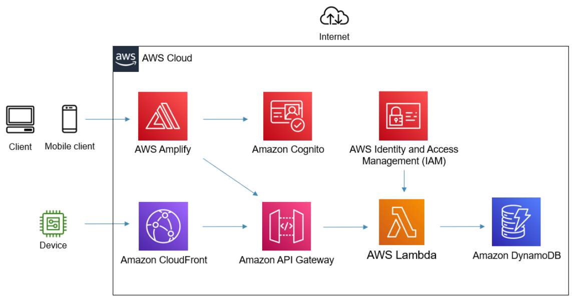

Figure 2: Architecture diagram of the online platform in AWS.

4 RESULTS

A total of 20 environmental monitoring nodes have been developed, from which various networks can be set up depending on the requirements of a specific location. From these, 10 nodes have direct connection capability to the Internet, in such a way that up to 10 networks could be made, each one with a peripheral node. These systems have already been preliminarily evaluated and the possibility of receiving data on environmental parameters remotely has been confirmed. During the system testing, we structured the devices as shown in Figure 3, where we can find six networks: 5 BLE networks with 3 nodes each one; and 1 ZigBee Network with 5 peripheral nodes.

The dimensions of the devices are 155.5x53.8x38.8 mm (Figure 4) . The system has an autonomy of 5 months using 30 minutes of sampling rate. Each node (peripheral and central) has sensors to measure temperature, relative humidity, illuminance and irradiance; and up to 5 central nodes

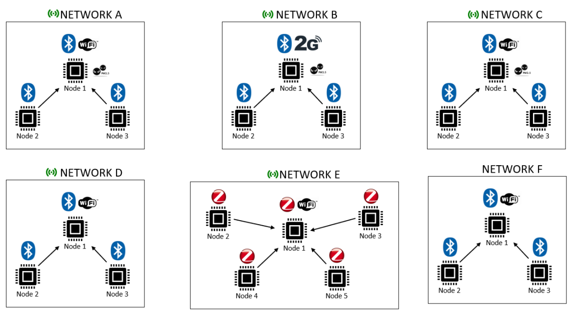

Figure 3: Networks Structure during testing.

Table 1: List of sensors and wireless modules.

Type	Part number	Manufacturer	Description
Sensor	SHT40	Sensirion	Temperature and RH sensor
	OPT3001	TI	Iluminance sensor
	OPT3002	TI	Irradiance sensor
	SPS30	Sensirion	PM sensor
Wireless module	RN4020	Microchip	BLE module
	E18-MS1-PCB	Ebyte	ZigBee module
	ESP32	Espressif	WiFi module
	SIM800L	SIMCOM	GPRS module

Figure 4: Hardware designed.

have the capacity to measure particulate matter. Each sensor is physically removable from the mainboard of each node due to the adaptive firmware that was programmed. The wireless modules (such as BLE, ZigBee, Wi-Fi, or GPRS) can also be physically removed from the main board, but in this case the firmware is different when using BLE or ZigBee due to incompatible I/O pins. The range of each wireless technology results in 35 meters for BLE and 60 meters for ZigBee.

Non-volatile EEPROM memory can store up to 6500 samples. A sample consists of the measurement of each sensor that the device has and the timestamp in which it was measured. In order to access these data, the device must be connected to the platform trough an USB connection. The Online Platform has been structured in four sections that include a centralized map, the visualization of the latest data from each node (including the option to change sampling and sending data rate), the retrieval of historical data and a dynamic menu that allows physical connection to each device via USB. This platform is exclusive only for the researches with a username and password. The Figure 5 shows data measured in two warehouses in a museum in Lima, Peru. This Figure also shows how can the user choose the sampling and sending data rate. The Figure 6 shows historical data measured inside a laboratory. In this section, the user can choose the environmental parameter from an specific device in a specific network.

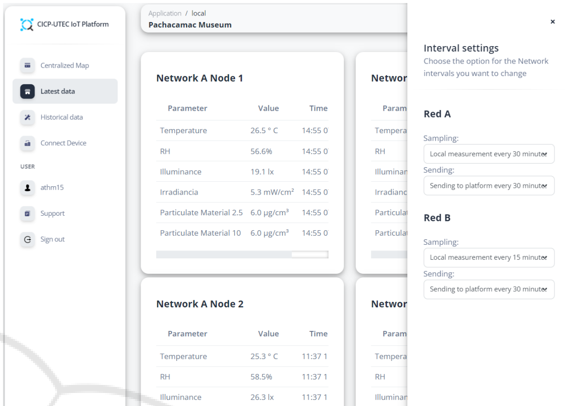

Figure 5: Online platform: latest data section.

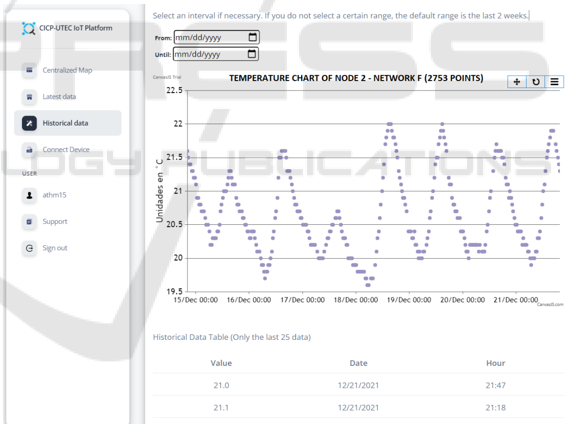

Figure 6: Online platform: historical data section.

5 CONCLUSIONS

In this paper, we present the design and implementation of a modular WSN system for heritage conservation. The system is battery powered and has long autonomy depending on the sampling rate the user choose for its application. The wide sensors set and the modular hardware allow measuring different environmental parameters corresponding to the most relevant for each type of material. The use of Wi-Fi and GPRS allows the use of this system in remote geographical locations and places with low technological resources. Finally, the easy-to-use online platform allows the visualisation and handling of latest and historical data of each node in network.

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REFERENCES

Al-Habal, A. and Khattab, A. (2019). *Ultra-Low Power Layered IoT Platform for Museum Content Conservation*. 31st International Conference on Microelectronics (ICM), Cairo.

Alsuhly, G. and Khattab, A. (2018). *An IoT Monitoring and Control Platform for Museum Content Conservation*. International Conference on Computer and Applications (ICCA), Beirut.

Eltresy, N., Dardeer, O., Al-Habal, A., Elhariri, E., Hassan, A., Khattab, A., Elsheakh, D., Taie, S., Mostafa, H., Elsadek, H., and Abdallah, E. (2019). *RF Energy Harvesting IoT System for Museum Ambience Control with Deep Learning*.

Morales, M. G. (2000). *Preventive conservation in museums. Theory and practice.* Organismo Autónomo Museos y Centros.

Peralta, L. M. R. R., Gouveia, B. A. I., de Sousa, D. J. G., and da Silva Alves, C. (2010). *Enabling museum's environmental monitorization based on lowcost WSNs*. NOTERE, Tozeur.

Shah, J. and Mishra, B. (2016). *Customized IoT enabled Wireless Sensing and Monitoring Platform for preservation of artwork in heritage buildings*. WiSPNET, Chennai.

Tse, R., Aguiari, D., Chou, K.-S., Su-Kit, T., Giusto, D., and Pau, G. (2018). *Monitoring cultural heritage buildings via low-cost edge computing/sensing platforms: the Biblioteca Joanina de Coimbra case study*.

Tse, R., Aguiari, D., Chou, K.-S., Su-Kit, T., Giusto, D., and Pau, G. (2020). *Self-adaptive Sensing IoT Platform for Conserving Historic Buildings and Collections in Museums*. IoTBDS.

Viani, F., Robol, F., Giarola, E., Polo, A., Massa, A., and Toscano, A. (2014). *Wireless monitoring of heterogeneous parameters in complex museum scenario*. IEEE Conference on Antenna Measurements Applications (CAMA).

Zhang, Y. and Ye, W. (2011). *esign and placement of light monitoring system in museums based on wireless sensor networks*. International Symposium on Advanced Control of Industrial Processes (ADCONIP), Hangzhou.