Environmental Monitoring Platform based on a Heterogeneous Wireless Sensor Network

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Abstract – **In museums, to conserve the existing artwork is a vital issue. To achieve this purpose, it is fundamental to monitor its environment, either in storage or exhibition rooms. The deployment of a Wireless Sensor Network (WSN) can help to implement these measurements continuously, in a real-time basis, and in a much easier and cheaper way than when using traditional measuring equipments and procedures. This is the main objective of the WISE-MUSE project, which uses WSNs for monitoring and automatically controlling museums' environment and structural health. In this paper, the implementation and the final results of the WISE-MUSE project, which was carried out in two particular museums located in Madeira Island, the Museum of Contemporary Art of Funchal and the Madeira Whale Museum, are described. Among other important contributions, we emphasize the development of new environmental monitoring and controlling devices, an emergency doors' controlling device, as well as the development of three new tools for monitoring, visualizing and managing WSNs, which bring some considerable advantages when compared with other commercially available solutions.**

Index Terms – **Artwork conservation, Environmental monitoring and control of museums, Preventive maintenance, Wireless Sensor Networks.**

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I. Introduction

NOWADAYS, museum managers are faced with the constant demand of gaining greater control of the indoor environment with the purpose of art preventive conservation, under increasing economic constraints. Those managers in charge of historic buildings have the added complexity of preserving not only the existing artwork but also the building's historic structure. On the other hand, it is very important to minimize the visual impact caused by monitoring systems in this type of environments for esthetical reasons. So, both kinds of protection must be accomplished with minimal intrusion from the monitoring system being installed and under increasing economic limitations.

The deployment of a WSN [1] in a museum can help to implement these measurements automatically, continuously, and in a much easier and cheaper way than using traditional measuring equipments. It causes almost no visual impact due to the small size of sensor nodes and to the absence of cables, what is extremely important in the context of a museum. Besides, it eliminates typical problems of traditional measuring equipments; there are no moving parts to break and it stays in calibration.

This leads us to the main purpose of the WISE-MUSE project: to employ WSNs for monitoring the environment and structure health of museums, and automatically control the critical environmental parameters.

The WISE-MUSE project was firstly developed for a contemporary art museum that is located on the premises of Fortaleza São Tiago, a fortress located in Madeira Island. In a subsequent phase, this project was extended to the Madeira Whale Museum, also located in the island.

This paper is organized as follows. Section 2 describes the related work in the area of monitoring the environment and structure of museums or historical buildings. Section 3 presents the need for environmental monitoring of museums and proposes the use of WSNs as a cheap and suitable solution. This section also presents several important issues of the WISE-MUSE project: its objectives, its architecture, and its application scenarios. Then, a new sensor node prototype is presented, a humidity control device is described, and a device for controlling the emergency doors of the museum is explained. This section also accounts for two tools developed specifically for WSNs: a visualization tool, and a sessions' monitoring tool. Finally, some experimental tests that were conducted to determine the final deployment are briefly described, and the problems identified during these experiments are outlined.

Section 4 and 5 respectively provide some conclusions and future work perspectives.

II. Related Work

There are some wireless devices commercially available that measure humidity and temperature [2], [3]; however, they are bigger and more expensive than most wireless sensor nodes.

Nowadays, there are deployments of WSNs in museums; nevertheless, the most common applications are, usually: to use WSNs for security reasons [4], [5]; or to monitor the number and distribution of visitors in the museum [6]; or for the creation of interactive museums [6], [7], [8].

Spinwave Systems offer a solution for preserving a building's architecture using WSNs [9]. Spinwave claim to provide precise control and monitoring of environmental variables, such as temperature and humidity, in buildings where wired sensors are not feasible or are prohibitively expensive. However, they do not monitor light or pollutants. Besides, their nodes are expensive. They also claim to ensure minimal disruption to building occupants and improved indoor climate; but, nodes are quite big for being applied in an environment where visual impact is of extreme importance.

Lee et *al.* [10] apply WSNs to monitor the environment of art galleries, but focusing in measuring only humidity and temperature. However, their paper focus on a different problem, i.e., on evaluating the efficiency of the ALOHA protocol without retransmission, when transmitting from sensor nodes to a base station. Del Curto & Raimondi [11] present a work where WSNs have been used for preserving historic buildings. Crossbow manufacturers [12] present two systems to be applied in museums and archives: a system that monitors humidity and temperature, the CLIMUS, and a system that controls the air conditioning unit, the REAQUIS. However, they do not use WSNs; they use wired sensors that are much bigger than wireless sensor nodes commercially available.

More recently, Ceriotti et *al.* [13] and Zonta et *al.* [14] have been working on the Torre Aquilla project that envisions the conservation of art and historic buildings, being the case that most closely matches our project. However, they also do not monitor pollutants and they are specifically focused in heritage buildings.

The main goal of the WISE-MUSE project is to create a WSN for monitoring and automatically controlling the most critical environmental parameters, which are humidity, temperature, and light, in museums (exposition rooms and storage rooms). Sensor nodes used in this project are smaller and cheaper than the ones used by Spinwave [9]. Pollutants are also of major concern for museum managers; thus, our project aims at monitoring pollutants. Besides, the WISE-MUSE project can be applied either to historical or new buildings, as will be demonstrated later in this paper. These factors are the basis for making our solution more suitable to the environmental monitoring of buildings.

Some of our preliminary work has been already published [15], but it refers to tests that were conducted using a commercial sensor. Another published paper [16] covers the first results of the WISE-MUSE project where all the presented results refer to experiments performed with a new wireless sensor node prototype that was developed by us, and a third paper [17] presents some final results of this project applied to the Fortaleza São Tiago museum.

III. The WISE-MUSE Project: Applying WSNs to Museums' Environmental Monitoring

The major goal of the WISE-MUSE project can be divided into several sub-goals, which comprise:

- To create a WSN for monitoring the most critical environmental parameters in museums (both in exposition and storage rooms).
- To monitor pollutants as they are also a major concern for museum managers.
- To give users and museum' managers the possibility of consulting the collected data in real time, via different data formats (e.g., graphs, tables, colour gradients, etc.), and consulting the historical reports whenever needed.
- To analyze data in order to verify its compliance with the art conservation rules. If a significant variation (below or above the required levels) on at least one of the measured parameters occurs, an alert has to be automatically sent to the user through a mobile phone (via SMS) or by e-mail, in order to increase the efficiency of this environmental monitoring system.
- To control the environmental conditions through the automatic control of the air conditioning and dehumidifying systems of the museum.
- To visualize collected data integrated in a 3D representation of the building.
- Still in what refers to security, to remotely monitor the state of the emergency doors of the museums, giving their managers and security personnel more awareness of their state, and avoiding their displacement to examine the state of each door.
- To implement low-cost devices for monitoring and controlling environmental parameters, as well as the state of emergency doors.

A. WISE-MUSE Architecture

The architecture of the WISE-MUSE project, which is represented in Figure 1, is composed by several modules. These modules were implemented by several students and other collaborators involved in the project.

The WSN is used not only to collect environmental data, but also to transport information relative to the Emergency Exit Controllers installed in the museums. The *Emergency Exit Controller* consists of a module that is responsible for remotely monitoring the state of the emergency doors. This is very important in the case of large buildings, avoiding that someone has to personally check the state of every emergency door of the building. This module has involved the development of a low-cost and small device for detecting the state of the emergency doors.

Two other important modules were created: the *Topology Management* and the *Collaborative WSNs' Modelling*. The topology management module deals with the practical deployment of the WSN, covering issues as the signal propagation study that needs to be conducted in order to determine the best possible deployment. The Collaborative WSNs Modelling module, in turn, approaches the modelling of each specific WSN using the specifications of the CWSN model [18].

The *Data Analyzer* transforms raw data collected by the sensor nodes into international system (IS) measuring units; this module is responsible for: 1) sending the RSSI (Received Signal Strength Indicator) parameter to the localization module that implements the localization algorithm, which will compute the positions of sensor nodes[1]; and 2) sending environmental data to the module that is responsible for the automatic control of air conditioning and dehumidifying devices.

The *Data Exporter* module is the responsible for the exportation of data to XML. Thus, the data output from the data analyzer is saved into an SQL database and, then, exported to XML files. The XML files are used not only as an input for the awareness tool but, also, for the web-based visualization tool and the sessions' management tool. The collection of XML files is saved in the database to compose the historical reports, which can be consulted whenever needed.

The *Automatic Control* module activates an automatic control device, which in turn actuates on the air conditioning and dehumidifying devices.

The *Notification System* alerts the museums' managers about abnormal values regarding the environmental parameters. Thus, when the monitored values go bellow or above the levels specified as acceptable, this system sends alerts to the managers, through SMS, MMS, or e-mail, using the *Sentinela security system* [19].

This architecture also comprises the development of three tools: a *3D awareness tool*, a web-based visualization tool, and a sessions' management tool. The three tools shown in the architecture were developed by MSc. students that conducted their works under the context of the WISE-MUSE project. One of the objectives of the WISE-MUSE project is to integrate these three tools, creating a complete monitoring and management platform for WSNs, what will be made in the near future. Among other reasons, the development of these tools was based in XML as a means of enabling this integration.

Note that the architecture proposed for the WISE-MUSE project is a generic one, since this project is intended to be applied to any type of museum scenario. This implies that some modules may not necessarily be implemented. For example, the WSNs deployed in Fortaleza São Tiago and Madeira Whale museums involved a small number of nodes. Therefore, the location of the sensor nodes was planned manually. Consequently, it was not necessary to implement the sensor localization module.

Figure 2 illustrates the phases involved in the environmental monitoring of a museum, in the context of the WISE-MUSE project. There are, essentially, five phases: it starts with the monitoring of temperature, humidity, light and pollutants; then, collected data is sent to a data repository; after that, data can be visualized in different formats (graphics, tables, colour gradients, etc.); afterwards, data is analyzed to verify its compliance with the art conservation rules; if it does not comply, alerts are sent to the Museum's staff; finally, the environment conditions are automatically controlled and, therefore, optimized accordingly to the analysis results.

B. Application Scenarios

The next two sections briefly describe the two museums the WISE-MUSE project was applied.

Museum of Contemporary Art of Funchal

Situated in the city of Funchal, on the island of Madeira, Fortaleza São Tiago is an irregular-shaped fortress from the 17th century, which today houses the Museum of Contemporary Art of Funchal.

Contemporary art uses a varied repertoire of materials and techniques. The use of new and different materials makes many works of art to be ephemeral, resulting in an increased need for monitoring the environment around these works to avoid their degradation.

Besides, Fortaleza São Tiago is located by the sea, as shown in Figure 3, what obviously influences the building's environment, especially in what regards to the humidity and temperature levels.

[1] The reasons for choosing a RSSI-based localization algorithm are outside the scope of this paper.

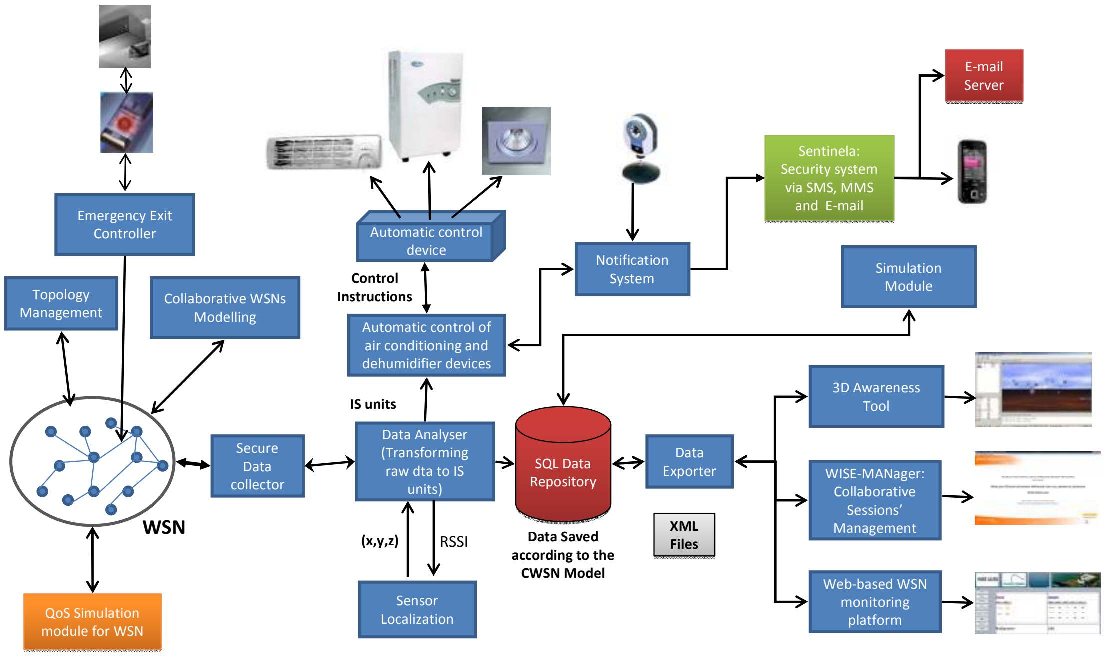


Figure 1. - Architecture of the WISE-MUSE Project.

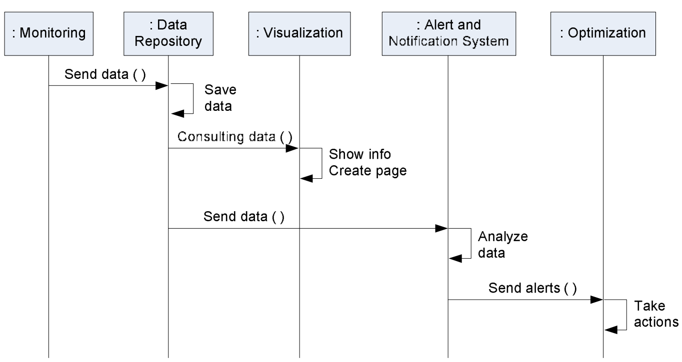


Figure 2. - Phases involved in the environmental monitoring of a museum.

In this particular museum, were environmental measurements were performed in a very rudimentary way using traditional and very expensive measuring equipments, and not as frequently as they should be, a WSN becomes a suitable and very attractive solution.

The experiments carried out in Fortaleza São Tiago and the deployed WSN correspond to a previous phase of the WISE-MUSE project, which was already published in [17]; therefore, it is not covered in this paper.

Madeira Whale Museum

The Whale Museum, which is illustrated in Figure 4, is a recently built museum located in a small fishing village, on Madeira Island. The museum focuses on the whale hunting activities that were part of many fishermen's lives for several decades. Whale hunting has been prohibited in Madeira since 1982. Interestingly, some of those fishermen are now helping to preserve the whales. Thus, they offered their hunting instruments to the Whale Museum. Some have even created new pieces of artwork from parts of old whale bones or teeth.

The WSN to be deployed has to undertake four different monitoring objectives that appear from the need of monitoring different types of artefacts and different areas of the museum. One of the objectives is to simply monitor the environment, namely temperature, humidity and light. Other two objectives are monitoring carbon monoxide (CO) and carbon dioxide (CO_2).

Figure 3. - Museum Fortaleza São Tiago and its irregular floor plants.

Figure 4. - Madeira Whale Museum

The fourth objective is to remotely monitor the state of the emergency doors of the museum, which is due to the large dimensions of the museum. In this particular case, the system has to detect and distinguish between three possible states: open, close, and emergency.

C. WISE-MUSE devices

This section presents the main electronic devices that have been implemented in the WISE-MUSE project, the WISE-MUSE sensor node and the monitoring device for the emergency doors' states.

WISE-MUSE sensor node

The new wireless sensor node developed by us is shown in Figure 5. It is designed specifically for environmental monitoring applications, but also considering the specific requirements of the museum, for example, reduced size and cost. This device emerges as the element that collects the environmental parameters, such as temperature, humidity, carbon dioxide (CO_2), carbon monoxide (CO) and light. In addition to these three parameters, it is possible to send the battery status (internal voltage) and the RSSI signal. The sensor node transmits the captured data to the base station, via RF.

The radio module used is the XBee or the XBee PRO, from the Digi manufacturer [20], which operates according to the ZigBee protocol [21], i.e., it is designed according to the IEEE 802.15.4 standard and to support the specific requirements of WSNs.

As explained before, to meet the requirements of the museum in terms of the physical location of the rooms that needed to be covered by the WSN and, consequently, in terms of transmission range it was necessary to employ a cluster-tree topology. As a result, the type of nodes that had to be deployed were some end devices, some routers and one coordinator. The end devices and the routers were developed by us, whereas the coordinator was acquired to DIGI manufacturer [20]. Nevertheless, the router created can also act as an end device whenever needed; in our experiments, it was used as both a router and as end device.

The differences between the end devices and the routers, at the hardware level, reside in the power supply module since the router has to be connected to an electricity socket; it can never be turned off or be in sleep mode. At the software level, there are also some differences since it has to be programmed as a ZigBee router, i.e., it has to receive data from the end devices that are wirelessly connected to it (i.e., end devices that are not under the range of the coordinator), and forward this data to the coordinator.

The WISE-MUSE sensor node, which corresponds to the ZigBee end device, was designed and built from scratch, with a set of components to meet the proposed requirements. This is a node of small dimensions, which causes minimum impact at the Museum. Its low cost is one of the strengths of this sensor node (less than 70€). Another advantage is its low energy consumption.

(a)

(b)

Figure 5. - WISE-MUSE sensor nodes. The node in fig. 5a) includes humidity, lux and temperature sensors; the node in fig. 5b) includes the previous sensors, but also CO_2 and CO sensors.

To be more precise, the WISE-MUSE sensor node has four main blocks:

- The *power unit*, which is composed of two AA batteries and a step-up circuit that allows to guarantee the supply of a constant power (3.3V) to the microcontroller XBee and to the sensors;
- The *microcontroller* that is the "brain" of the node. It receives data from multiple individual sensors, processes it and, then, sends it through an XBee RF card;
- Four specific *sensors*: a light sensor that measures the brightness in the rooms of the Museum, a CO_2 sensor that measures the carbon dioxide gas (CO_2), a CO sensor that measures the carbon monoxide gas (CO), and a sensor that measures both temperature and humidity;
- The *transceiver* module that transmits the collected data.

To guarantee an easy programming of the microcontroller, it was designed to be easily connected to a programmer, using the AVR-ISP500 protocol[2]. Using this connection, the code can be easily updated whenever necessary. The chosen microcontroller is the Atmega 168 [22], since it presents a set of characteristics that fits almost perfectly all our purposes; its

[2] AVR-ISP500 is USB low cost in-system programmer for AVR microcontrollers. It implements the STK500v2 protocol as defined by Atmel [22]. ISP stands for In-System Programmable.

low cost, low consumption and high performance are the main reasons for this choice. The chosen sensor elements are the SHT15 humidity and the temperature sensor, from the Sensirion Company [23], the C20 carbon dioxide sensor, from the GSS Company (GSS, 2010), the TGS5042 carbon monoxide sensor, from the Figaro Company (Figaro, 2007), and the S1087 photocell, from the Hamamatsu Company [24].

The C20 uses non-dispersive (NDIR) LED technology to detect and monitor the presence of carbon dioxide gas. The TGS5042 sensor converts the direct current in proportion to gas concentration measured and returns a value of voltage to the microcontroller, which is then converted to the parts per million (ppm) unit values. The photocell captures the sunlight and returns a value of voltage to the microcontroller, which is then converted to the intensity of sunlight (LUX) unit values. The SHT15 sensor calculates the relative humidity and temperature values. This is a totally calibrated CMOS industrial device, which allows a good stability at low cost. Its accuracy is much appropriated considering the requirements of the project (+/-2% for humidity, and +/-0.3ºC for temperature).

In order to meet the power autonomy requirements of a sensor node, each node is powered by two AA batteries (1.5V each). These batteries have a capacity of 2450mAh and an output voltage of 1.5V. Their technology is the Nickel Metal hydride and they weight only 28g. Our goal is that the batteries last between 2 and 3 months, but this is still being tested.

The XBee or XBee PRO RF transmission modules were chosen because they require minimal power and because they provide a real and consistent delivery of information between devices, operating at the 2.4GHz ISM frequency band. Although there are other options for RF transmission modules with lower power consumption, the popularity and characteristics of the XBee modules determined our choice.

The WISE-MUSE sensor node has been compared with some commercial sensor nodes that could be used in the environmental monitoring of museums. The characteristics of the nodes were considered as described in the manufacturers' datasheets.

At the sensing module level, the analysed sensors are quite similar. Most of the modules use the SHT15 or STH11 sensors, by Sensirion [23], and their accuracy does not vary much, about +/-0.3ºC for temperature and about +/-3% for relative humidity.

Almost all nodes collect light, temperature and humidity, with the exception of the Mica2 Sensor Board MTS101CA [12] that cannot measure humidity. The Mica Z [12] reads other kind of data, which is not necessary in this application scenario. Besides, Mica Z has the disadvantage of a higher cost.

Regarding the microcontroller there are some considerable differences. Most microcontrollers are manufactured by Atmel [22], except for the Tmote Sky, which is manufactured by Sentilla [25]. Atmega devices [22] have many features in common with our prototype. The WISE-MUSE prototype presents a flash memory with lower capacity; however, this factor should not be seen as a disadvantage since it conducts to a reduction on the amount of code programmed into the microcontroller. Consequently, the microcontroller has to process less amount of code what leads to a lower power consumption of the node. Therefore, it is not necessary a flash memory with more capacity. It was verified that the energy consumption of the WISE-MUSE prototype can be reduced when operating at a frequency of 1MHz. In these conditions, its consumption can be decreased to 0.3mA, which is a value smaller than for the other devices.

The Mica motes [12] must be programmed through a base station, which involves an additional cost. The Tmote Sky and the WISE-MUSE nodes offer an advantage over the others; they are more easily programmed. The Tmote is programmed using USB, while the WISE-MUSE prototype is programmed using the Olimex programmer that uses the AVR-ISP500 protocol.

In relation to the transceivers of each node, all of them use the IEEE.802.15.4 protocol, which is the most appropriate protocol for WSNs. The Mica 2 operates in the 868/916Mhhz, 433MHz or 315MHz ranges, while the others use the 2.4GHz range.

Thus, the XBee module used in the WISE-MUSE prototype is well ranked due to its higher power transmission. Using the XBee-PRO allows an even higher transmission range what is an advantage when comparing to the other nodes. Its disadvantage regards the energy consumption; however, the XBee is designed to enter in the sleep mode, waking up only in pre-defined time intervals to send data; this way, the problem of energy consumption is minimized.

Looking to the sensor nodes as a whole, they all have similar dimensions, but the WISE-MUSE mote has a very low cost when compared to the Mica motes.

In conclusion, it is important to note that the module created was designed and built for the specific indoor environmental monitoring at the Museum, presenting a number of advantages that may be attractive for this monitoring application, where its skills are within the requirements of the final client. Moreover, this new sensor node brings some advantages when compared to other commercially available solutions, such as low cost, small size, low power consumption, and higher transmission range.

Monitoring device for the emergency doors

One of the main concerns of the Whale Museum is to monitor the emergency doors' states (open, close, or emergency). At the moment, these states are detected by the Door terminal DORMA TL. This terminal, located next to each emergency door, detects the state of the doors and lights up the LEDs in different colours to represent different states: green for open, red for close, and yellow in emergency (as depicted in Figure 6). This kind of solution is limited because it notifies the doors' state locally, next to the door. Since the Whale Museum is located in a large building, the security personnel have to displace through the museum to examine the emergency doors' state. Therefore, it is necessary to implement a centralized system to monitor the emergency doors in real time.

Thus, the monitoring device for emergency doors (Figure 7) was created based on the following objectives:

- To detect door's state changes and to transmit this information to the WSN, free of errors, and in real time.
- To have small dimensions for being installed inside the DORMA TL module.
- To have low cost.

Figure 6. - Door Terminal DORMA TL representing different door's states.

Figure 7. - State Monitoring device for the emergency doors.

This device collects the door's state from the TL-S TMS unit on the door Terminal DORMA and sends it to the XBEE module that transmits the state to the WSN (Figure 8). Then, this state can be visualized on the WISE-MUSE Web platform. Thus the advantages of the doors' monitoring device are:

- Low cost;
- Small dimensions;
- It does not modify the regular operation of the DORMA module;
- It can be easily adapted for other systems and other emergency parameters, like the smoke alarm and/or door intrusion.

D. WISE-MUSE Web platform

The WISE-MUSE Web platform was developed using PHP language, it allows remote monitoring via the Internet in real time of all environmental sensors and emergency doors that are installed in the museum. In addition, this platform makes it possible to obtain an historical report of all the sensors and doors. This data can be exported to Word and/or Excel format, generating dynamic charts with the data obtained from the environmental monitoring sensors and emergency doors.

When the platform is initialized, it immediately provides a general view of the status of all emergency doors and sensors, thus enabling rapid identification of any anomaly (Figure 9). Using the left side of the main menu, it is possible to navigate to get more detailed information of the emergency doors and sensors nodes, where we can explore each of the museum's floors and generate historical reports and graphs from the data collected by WSN (Figures 10, 11 and 12).

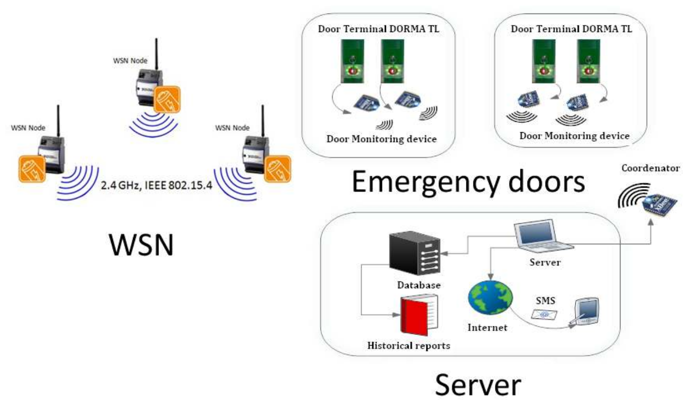


Figure 8. - Integration of doors monitoring device with the WSN.

Figure 9. - Main page.

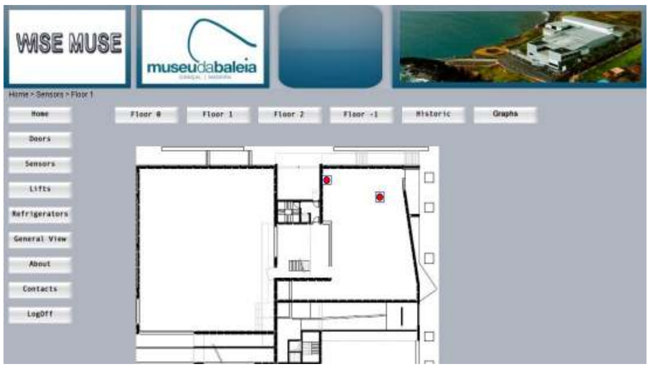


Figure 10. - Floor plants

Figure 11. - Temperature graphic generated during 24 hours.

Figure 12. - Historical report of sensor node 2.

Currently, there are some commercial solutions that allow WSNs monitoring; however, the WISE–MUSE Web platform has some specific characteristics that distinguish it from the others. Table 2 shows the main advantages of this platform comparing to the most representative commercial applications.

As we can see, the platform WISE-MUSE presents itself as the most complete in the features offered to users in museum contexts. Note that, currently, there is no centralized platform that allows efficient monitoring of other wireless devices.

E. Notification System

In the case the sensor nodes detect parameters that are not in compliance with the art conservation rules, or if one or more emergency doors are in emergency state, the notification system sends alarm messages to the museum's managers to warn about the problem. In order to be an inexpensive solution, the notification system uses the API Google Calendar, which allows users to create events on the calendar, as well as the creation of alarms and notifications for those events. These events are sent directly to the e-mail and mobile phone (via SMS) of the user for free.

Thus, when a problem arises for which it is necessary to send a notification, the system first performs a search in the database in order to collect information about the users authorized to receive notifications. This allows notifications to be sent to all users on the database. Then, the system creates an event on the calendar, with the current date. Thus a notification is sent to the users with a maximum delay of 1 minute.

Table 2. Comparing WISE-MUSE visualization tool to other commercial solutions

Features	***WISE-MUSE***	***WiSense*** [26]	***SNA*** [27]	***Senso Net*** [28]	***WebSensys*** [29]
Generation and export historical reports	✓	✗	✗	✗	✓
Graphics generation	✓	✓	✗	✓	✓
E-mail notification	✓	✓	✗	✓	✓
SMS notification	✓	✓	✗	✓	✗
Open Source	✓	✗	✗	✗	✓
Location plant	✓	✓	✓	✓	✓
Platform Independent (S.O.)	✓	✗	✗	✗	✓
Real time	✓	✓	✓	✓	✓
Monitoring Other Wireless Devices	✓	✗	✗	✗	✗

The platform received an extremely positive evaluation from museum's manager and security personnel. It was considered very easy to use, attractive, reliable and user friendly. Besides, they did not highlight any problems regarding its usability.

F. WISE-MANager

In order to implement and validate the CWSN model, we have implemented a collaborative sessions' management tool, called WISE-MANager (WIreless SEnsor networks MANager for collaborative sessions). The WISE-MANager tool allows creating, monitoring and managing collaborative sessions using the Zigbee protocol [21]. The purpose of using collaborative sessions is to provide a better interaction between the user and the WSN, since the user can customize the type of monitoring to be carried out (sensor node, phenomenon, or time interval of monitoring), and query the network and its components. This way, the WISE-MANager tool (Figure 13) increases the flexibility of the WSN.

The WISE-MANager tool was implemented in Java and it is Zigbee-compliant. It is composed of two main modules: (i) Collaborative Sessions Management; and (ii) WSN Management.

The first module, collaborative sessions' management, allows creating and managing collaborative sessions inside a WSN. Users can configure the session's parameters (id, description, etc.), the sensor nodes that will make part of that session, the monitoring period, and the phenomena to be monitored (Figure 14).

After creating the session, the user can visualize and change the session's parameters. Moreover, he can also start and stop the session's monitoring at any moment, monitor the sessions that are in an "open" state (Figure 15), and delete them. Thus, sessions can be opened manually by the user or automatically according to the session's monitoring schedule.

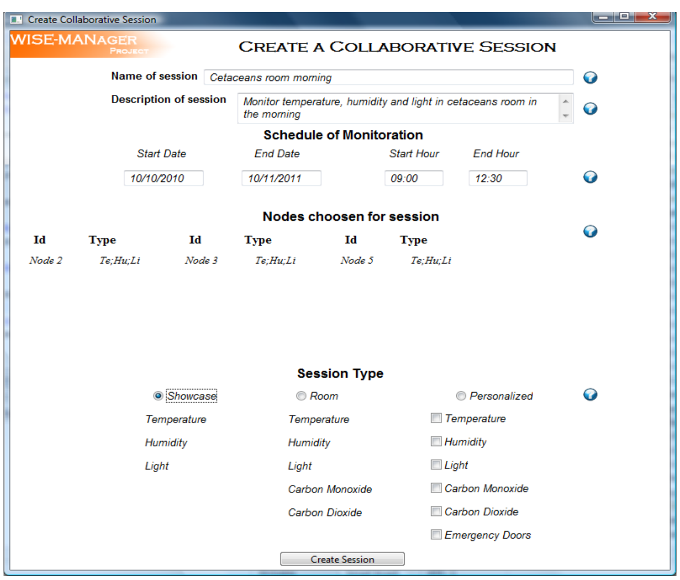


Figure 13. - Creating collaborative sessions using the WISE-MANager tool.

Moreover, the user can export the session's data to a Word document, choosing the session and the monitoring time interval. The document will contain the session's parameters as well as the data received during the session (Figure 16).

In the second module, named WSN Management, the user can choose a serial port where the WSN's coordinator is connected. Using this module, the user can see the WSN information, like the PAN ID, the network channel, and the network components (routers, end devices, coordinator, etc.) and its parameters. Moreover, the user can modify the device's identifier (Figure 17).

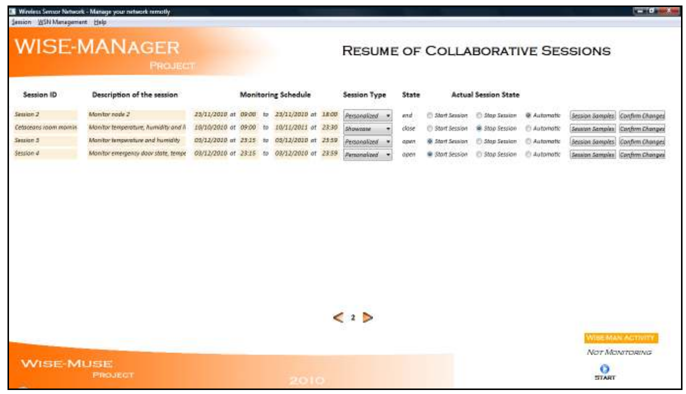


Figure 14. - Opened sessions.

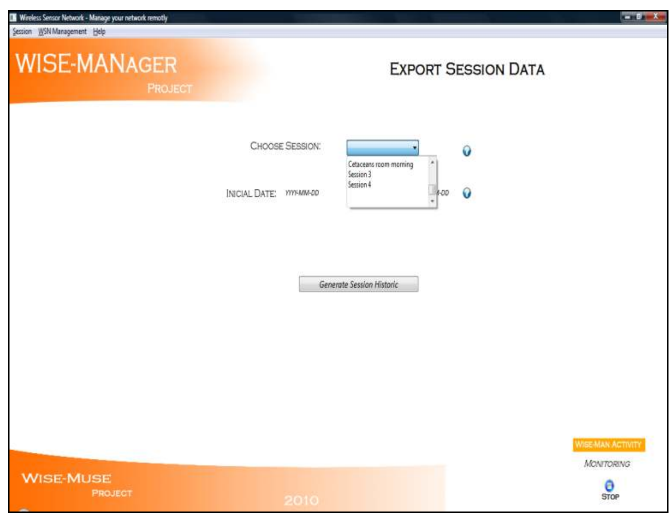


Figure 15. - Export Data.

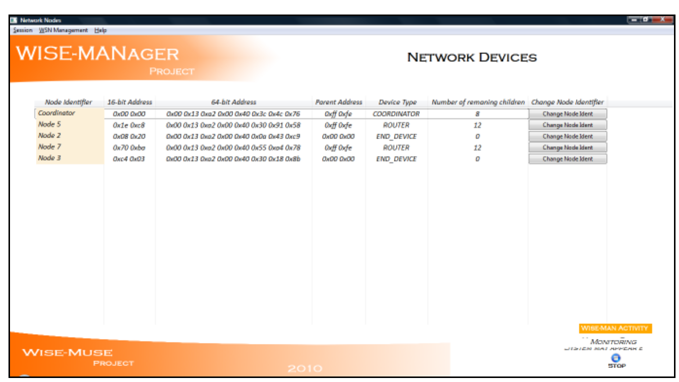
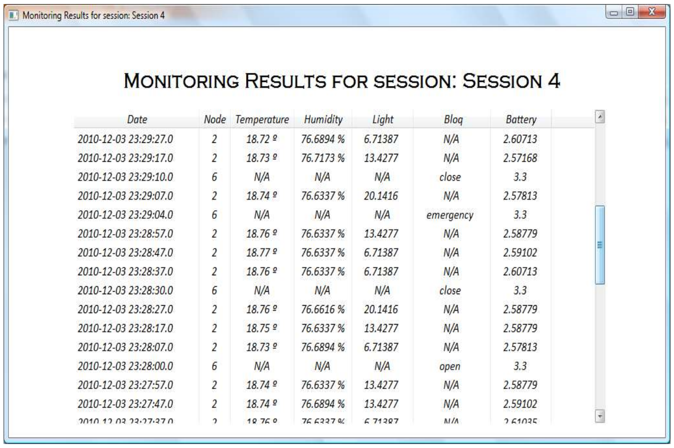


Figure 16. - Detecting WSN devices.



Monitoring Results for session: Session 4

MONITORING RESULTS FOR SESSION: SESSION 4

Date	Node	Temperature	Humidity	Light	Bloq	Battery
2010-12-03 23:29:27.0	2	18.72 º	76.6894 %	6.71387	N/A	2.60713
2010-12-03 23:29:17.0	2	18.73 º	76.7173 %	13.4277	N/A	2.57168
2010-12-03 23:29:10.0	6	N/A	N/A	N/A	close	3.3
2010-12-03 23:29:07.0	2	18.74 º	76.6337 %	20.1416	N/A	2.57813
2010-12-03 23:29:04.0	6	N/A	N/A	N/A	emergency	3.3
2010-12-03 23:28:57.0	2	18.76 º	76.6337 %	13.4277	N/A	2.58779
2010-12-03 23:28:47.0	2	18.77 º	76.6337 %	6.71387	N/A	2.59102
2010-12-03 23:28:37.0	2	18.76 º	76.6337 %	6.71387	N/A	2.60713
2010-12-03 23:28:30.0	6	N/A	N/A	N/A	close	3.3
2010-12-03 23:28:27.0	2	18.76 º	76.6616 %	20.1416	N/A	2.58779
2010-12-03 23:28:17.0	2	18.75 º	76.6337 %	13.4277	N/A	2.58779
2010-12-03 23:28:07.0	2	18.73 º	76.6894 %	6.71387	N/A	2.57813
2010-12-03 23:28:00.0	6	N/A	N/A	N/A	open	3.3
2010-12-03 23:27:57.0	2	18.74 º	76.6337 %	13.4277	N/A	2.58779
2010-12-03 23:27:47.0	2	18.74 º	76.6894 %	13.4277	N/A	2.59102

Figure 17. - Data collected by the Session 4.

Advantages and disadvantages of WISE-MANager tool

After analyzing the most important management tools for WSN, we verified that most of the tools are able to query the WSN. On the other hand, none of these tools can create or use collaborative sessions to manage the WSN. The WISE-MANager tool allows customizing the monitoring activity and defining the session's parameters.

Moreover, the WISE-MANager tool allows the user to control the network and inquire the WSN, getting information like communication channel, network ID, PAN ID, etc. It is also possible to detect the network's devices and change their identifiers.

Through collaborative sessions, the WISE-MANager tool enhances collaboration between the user and the network. Thus, the network is more flexible since the user can customize the collaboration, choosing different nodes to monitor different phenomena, and the monitoring time interval. Therefore, the network topology can be dynamic, since nodes can be active or inactive, according to the collaborative session's state. Additionally, this feature allows the energy saving of the network nodes.

G. *Heterogeneous WSN Deployment*

According to the monitoring needs defined by the museum manager, the WSN has to be deployed in 4 floors of the museum, from floor -1 to floor 2. Besides, different rooms have different monitoring needs, as distinct artefacts are exposed in each room. Therefore, it was necessary to evaluate, together with the manager of the museum, the monitoring needs of each room and of each type of exposed artefacts.

Thus, it was necessary to conduct a few experimental tests in this museum to determine:

- The number of nodes necessary to cover the areas that need to be monitored in the museum;
- Where to locate these nodes; and,
- The different types of nodes that need to be deployed, since the distinct areas of the museum have different monitoring needs.

Deployed WSN

An empirical study of signal propagation was held in Whale's Museum, in order to get the best network deployment, determining the final network's topology. In addition, it was made the network's coverage map, listing the best and worst places of signal propagation. The monitoring system that will be installed in this museum will use two types of devices: i) a sensor node that collects the environmental data, such as, temperature, luminosity, humidity and pollutants; and; ii) a door monitoring device that detects the emergency doors' state.

On floor 0 of the Whale Museum, we intend to monitor the cetacean's room, the video projection room, as well as the whaling room and the atrium. This floor has nine emergency door terminals. The cetacean's room is the larger room to monitor, occupying three floors, has several obstacles: two whales in the middle of the room, a submarine and several dolphins along the room suspended by the ceiling. In the projection video room, there are several chairs arranged as an amphitheater and a large screen. The whaling room has several paintings, a whale and a boat, as well as several showcases. The atrium is a common area that has several paintings.

The propagation study consisted in measuring the RSSI in these museum rooms. In this study three types of devices were considered: end-device, router and coordinator. The end-device will monitor the environment, for example temperature, the router transmits the data until the coordinator. The coordinator was installed in the floor 0. This device will be connected to the server's USB port, where the visualization platform is installed.

The test devices were placed approximately 2m from the ground and near the wall, in order to evaluate the XBee's behaviour.

The X-CTU software, from Digi [20], was used to configure the devices as router, coordinator and end-device.

The XBee series 2 pro has an indoor range of 100 m and receive sensitivity of -102 dBm. As to the XBee series 2, the indoor range is 40 m and the receive sensitivity of -96 dBm. It is worth noting that the operating frequency of both XBee is 2.4 GHz.

As the CO and CO_2 sensors are significantly more expensive when comparing to light and temperature/humidity sensors, decreasing the number of sensor nodes that use these components has allowed to decrease the cost of the final solution. Consequently, to meet the monitoring needs of the museum and to reduce the cost of the WSN to be installed, different sensor nodes were created.

Several signal measurements were carried out to determine the number of end devices and routers necessary to cover the extensive area to monitor, and the respective location.

Thus, the WSN deployed in all the exhibition rooms of the Whale Museum is composed by:

- 39 end devices: 14 end devices that simply monitor temperature, humidity and light, 14 end devices that monitor end devices that monitor and CO_2, and 11 end devices that monitor end devices that monitor and CO. All the end devices also monitor the level of their own batteries.
- 16 routers;
- 19 emergency doors' controllers; and,
- 1 coordinator

Figure 18 exhibits the sensor nodes final location. In this figure the emergency door blockers as well as the routers of floor 0 are shown.

Identified Problems

Since the Whale Museum is installed in a new building, the problems that have emerged are of different nature when compared with Fortaleza São Tiago. Exception is made to the need of minimizing the impact caused by the monitoring system to be installed in both museums. This is a common problem in all museums around the world.

During the first experiments carried out in the Madeira Whale Museum, nodes were equipped with XBee series 2 radio modules. Several problems emerged, namely:

- Interference with the audio system of the museum.
- About 70% of packet loss when the microwave located in the kitchen is turned on.
- The need to deploy a considerable amount of routers to ensure communication with the coordinator, given the extensive area that the WSN has to cover.

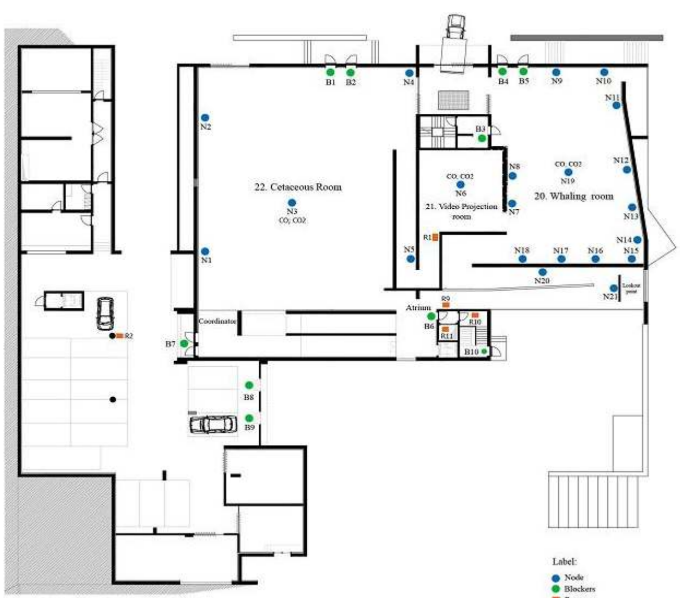


Figure 18. - Final location of node sensors (in blue), door terminals DORMA (in green) and routers (in orange).

These problems have mostly disappeared after nodes were equipped with XBee series 2 PRO radio modules, which have a higher transmitting RF power (60 mW vs. 1mW) and a higher receive sensitivity (-100dBm vs. -92dBm) than XBee series 2 modules.

To overcome the interference problem caused by the microwave device, a possible solution is to only turn on the microwave when the deployed WSN is not transmitting data. In fact, the WSN is scheduled to transmit data every 10 minutes; this means that the microwave should be turned on only in the 10 minutes intervals. This implies informing the kitchen personnel of this need.

Other types of problems were experienced, such as:

- According to the museum's managers, the monitoring devices, either end devices or routers, should be located at a minimum height of 2m from the floor to avoid its possible damage by malicious visitors. We have analysed some documentation about air quality monitoring, namely about CO and CO_2 monitoring. It was verified that to obtain more representative results, CO should be ideally monitored at the knees' height or at the height of someone lying in a bed [30], whereas CO_2 should be ideally monitored higher on the wall or ceiling [31]. To avoid that devices are reached by visitors, these have to be located at a considerable height from the floor.
- The monitoring devices, either end devices or routers, should be located close to electricity sockets that will electrically feed them, avoiding the need of using batteries and of frequently changing them. This is perfectly reasonable since this is an indoor environment. However, it implies that the location of the monitoring devices is more carefully planned, since it does not depend merely on RSSI measurements. Avoiding the use of batteries allows saving time and money to the museum employees and managers.
- To decrease the impact of the monitoring devices, the museum managers wanted to enclose all devices inside grey metal boxes. Nevertheless, these boxes do not enable signal propagation. Instead, these boxes were built in a plastic material (Polyvinyl chloride, commonly abbreviated PVC) with small holes located near the light and humidity/temperature sensors to ensure that these sensors can correctly measure these environmental parameters.
- The coordinator has to be connected to a server that is located in a small room placed below some stairs, and lined with wood, making the signal propagation more difficult. This brought the need to deploy several routers to ensure communication between the WSN and the coordinator.
- Some whale hunt artefacts are kept inside showcases made of glass, in a room located in floor 0. To ensure communication between the end devices and the routers in the referred room, it was necessary to locate the sensors inside the showcases, whereas the antennas and radios

were located outside the showcases. These devices are also supplied by electricity sockets.

- Finally, the data frames generated by the devices that were installed in the emergency doors to detect the door state's changes are different from the data frames generated by the end devices. This caused the need of reprogramming the coordinator so that it can distinguish between the two types of frames, and also filter some trash frames that are being generated.

IV. Conclusion

In this paper, some final results of the WISE MUSE project, which regards the deployment of a WSN for automatically and continuously monitoring and control the environment of a museum, were presented. The employment of WSNs to this context was compared with related commercial solutions, being outlined its advantages. Besides being a simpler solution, the use of WSNs for environmental monitoring of a museum is, indeed, a more reliable solution. It is also less expensive than manual data collection or than a wired central monitoring system.

The deployed WSN was described and, then, modelled and represented using the CWSN graph-based formal model, which brings several advantages to the users and network managers.

This project has proposed several contributions:

- The WISE-MUSE sensor node, a new, smaller and cheaper sensor node for environmental monitoring applications;
- The monitoring device for emergency doors that detects the door's state and sends it to the WSN;
- The WISE-MUSE Web Platform, a Web-based visualization system that allows environmental monitoring and notification (via SMS and e-mail) in real-time;
- The WISE-MANager, a collaborative sessions' management tool.

Furthermore, in order to increase the efficiency of this environmental monitoring system, by maintaining the humidity at more constant levels, a system that automatically controls the dehumidifying devices was implemented [17].

In the near future, we intend to bring together the three described tools in order to create an integrated and complete monitoring, visualization, and management solution for WSNs.

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