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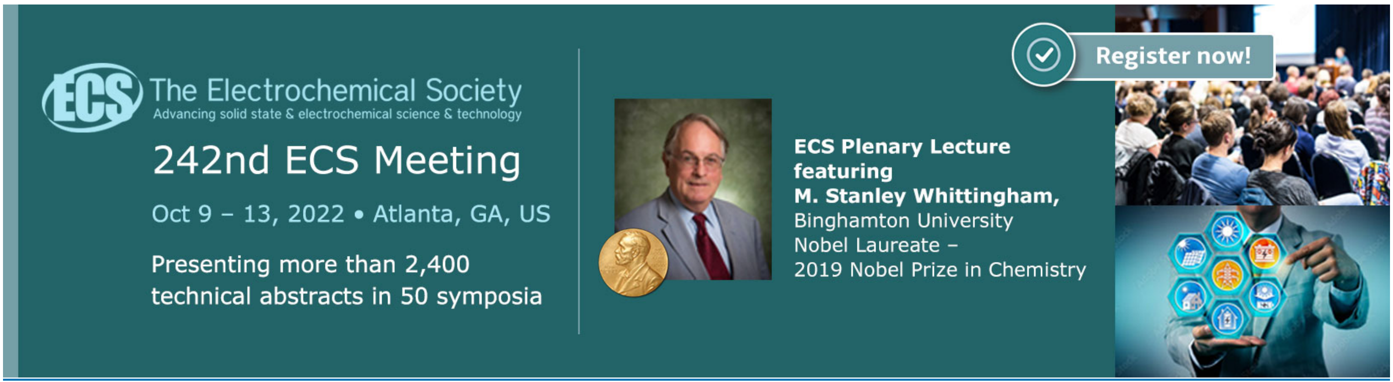

Environmental monitoring solution for cultural heritage

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Abstract. Environmental monitoring is crucial factor in the safeguard and conservation of the cultural heritage. Unsuitable environmental conditions can easily accelerate the degradation of several materials and, as consequence, damage the stored artifacts. Moreover, environmental conditions can easily change in an unpredictable way and, therefore, the employment of an environmental monitoring system is mandatory in almost all locations, including museums, storage rooms and outdoor exhibitions. This paper tries to explain the main constraints required for environmental monitoring in the cultural heritage field. Moreover, a novel distributed monitoring system, developed at Politecnico di Torino, is described and compared to several solutions that are commercially available. The proposed solution demonstrated excellent characteristics which satisfy the requirements of environmental monitoring in the cultural heritage at a very competitive cost.

1. Introduction

Preventive conservation is intended as the set of actions aimed at improving the conservation of artifacts of historical or artistic interest so that the possibility of either any alteration or degradation of them is avoided as much as possible [1]. The strategies employed by curators and conservators can be different. In particular, some of them act on the artifact itself (restoration and protection) while others rely on the environment hosting the artifact by avoiding unsafe conditions which can affect the conservation state of the objects.

In particular, the environmental conditions are extremely important due to the fact that often improper conditions can either initiate several degradation processes or accelerate the ones already active on the artifacts. In contrast, optimal storage conditions can sometimes slower down the active degradation processes and improve the effectiveness of the artifact preservation.

Moreover, it should be considered that an effective environmental monitoring is a compulsory requirement during artifact transportation and exhibition loans.

Several are the critical environmental parameters which can severely affect the conservation state of an artifact, and these depend from the artifact type, its conservation state and the material which compose the artifact itself. As an example, several gases, normally present in the atmosphere, and in general air pollutants such as particulates (both organic and inorganic), sulfur dioxide, ozone, nitrogen oxides, formaldehyde and several volatile acids, can severely effect almost all artifact types also in concentrations of few part per billion [2]. Also light exposure (both visible and UV) can have negative effects on several types of artifacts including paintings and paper documents. Vibrations and mechanical shocks can be critical during transportation of fragile artifacts as well. Thus, an effective environmental monitoring can be very useful for detecting any condition that can be potentially dangerous for the artifacts.

However, among all the possible parameters, temperature and relative humidity are known for affecting almost any kind of material and, in particular, metals, textiles, papers and paintings.

It is also important to note that such environmental parameters can easily change at short distances especially in indoor location, where the building structure, the presence of air conditioning systems and windows can easily generate significant gradients also at few meter of distance. Furthermore, the periodical openings of the showcases for maintenance, when carried out in the wrong conditions (i.e. when external environmental conditions are not suitable), can be extremely dangerous because, when the showcase will be closed, such unsuitable conditions will maintain inside the showcase for long time. Therefore, a distributed monitoring system is required in almost all cases with the possibility to deploy a sufficient number of sensors in the environment. Furthermore, other constraints can be critical in the cultural heritage field. The system should provide a sufficient flexibility in the deployment and management, and it should avoid any impairment for the visitor fruition of the artifacts. As a consequence, it is required a battery power supply for the sensors and a wireless communication interface in order to avoid any cabling during the deployment and data acquisition. Physical dimensions of the sensors should be very small so that the devices can be hidden easily in the showcases. Sensor operative life should be taken in proper consideration as well, because a poor design can involve high power consumption and the necessity of frequently either replace or recharge the sensor batteries.

Data fruition it is also quite important. Different kind of devices can be, therefore, employed according to the specific application and the monitored location.

In some situations it can be sufficient to access the data only periodically. In such cases, data loggers can be a valid solution. Data loggers are devices that are able to autonomously acquire the environmental parameters and store them into a non-volatile memory. Such devices are not suitable for a real time monitoring and they often require a physical access to the devices for downloading the data (i.e. by using an USB connection with a PC).

In other applications, instead, it is required to access the acquired data in real time. This involves the necessity to provide the devices with a communication interface, able to transfer the data in real time toward some specific client and lets the users access the data in a friendly way. Typically, such monitoring systems have the capability of automatically identify unsafe conditions and send specific alarms to the users. This kind of devices are more complex and expensive than simple data loggers and often they require a costly deployment and installation procedure.

Another important factor, often underestimated, is the reliability of the sensors and of the acquired data. Sensors typically are affected by drifts, which modify the sensor response with the time. As a consequence of such drifts, the data acquired can be affected by an increasing uncertainty which can become unacceptable after several months of operation. Therefore, the monitoring system should allow users to carry out periodical calibrations which, preferably, should avoid the removal of the sensors from the location.

All the described constraints are not typically addressed by generic monitoring systems and, therefore, specific commercial solutions have been proposed in last years. However, these monitoring systems are typically quite expensive and they require several different type of sensors in order to satisfy the requirements of a specific application.

2. The proposed solution

A distributed monitoring system has been developed recently at Politecnico di Torino [3, 4]. This solution tries to satisfy most of the above described constraints and it has been successfully applied in several monitoring campaigns in the cultural heritage field.

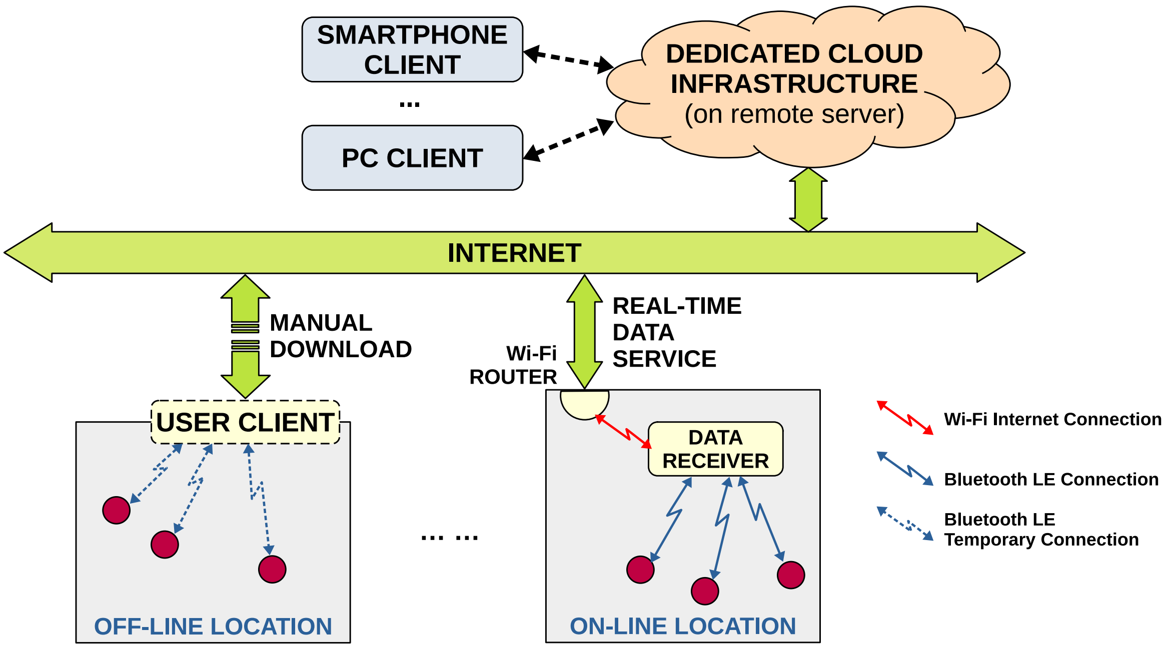

Figure 1. Architecture of the proposed monitoring system showing the data flow both in off-line and on-line locations.

The system architecture is shown in Fig. 1. The monitoring system is able to perform distributed measurements by employing small battery-powered sensing nodes, which support the Bluetooth Low-Energy 4.1 (BLE) wireless protocol. Each sensing node is identified by a unique ID and is able to acquire both temperature and relative humidity at specific time intervals that can be selected from the user in the range of 5 s to several hours.

The sensing nodes, shown in Fig.2-A and in Fig.2-B, are based on a ultra-low power microcontroller which embeds a BLE wireless transceiver. The node features also a non-volatile memory, which is employed to locally store all the acquired data up to a maximum of 135000 measurements. The node employs a small lithium battery of type CR2477 able to power the node for about 3 years with a measurement interval of 10 min. The sensing node has dimensions of about 35 mm × 16 mm, including the battery and the 3D-printed enclosure. Such dimensions together with the possibility of changing the enclosure color make easy to hide the sensor inside showcases. Temperature and relative humidity are measured by the digital sensor SHT21 (Sensirion) which provides a typical uncertainty of 0.3 °C for temperature and 2% for relative humidity. The sensing node have a set of free IO pins (both analog and digital) which can be used to interface additional devices such as light and UV sensors, gas sensors and accelerometers for monitoring the vibrations. Therefore, the system can be employed for carrying out a multi-parameter environmental monitoring by using a single sensing device.

The measured data are directly stored on the embedded memory as soon as they are acquired and this avoids any possible data loss. Moreover, the nodes feature a BLE Interface which can be used both to configure the node operation and to download the acquired data. This feature allows the nodes to operate both as stand-alone data loggers and as wireless real-time sensors which are able to connect to any BLE-compatible device, such as smarthphones and laptops. In particular, data download can be carried out in two main modes: on-line mode and off-line mode.

The on-line mode requires the sensing nodes to be deployed in the location together with a

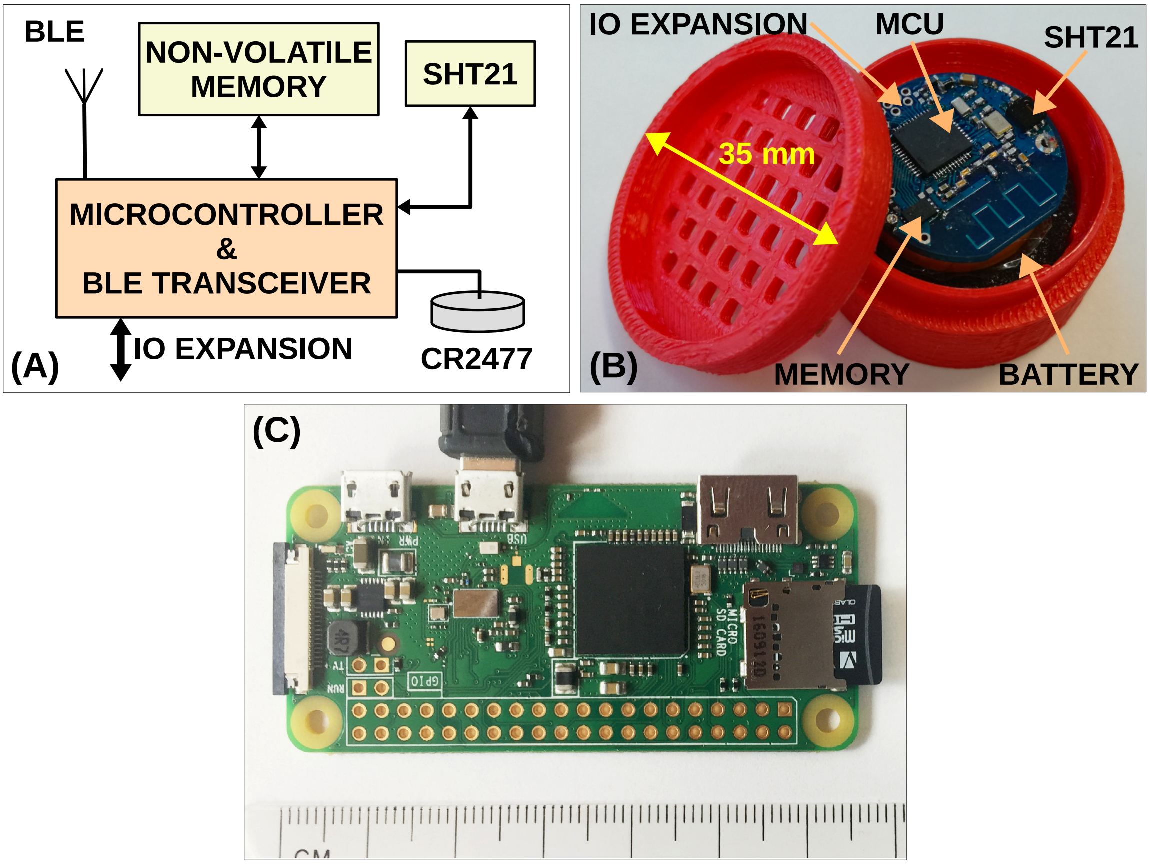

Figure 2. Block diagram of the sensing nodes (A) and a sensing node prototype with its 3D-printed enclosure (B). RaspberryPI Zero Board employed as data receiver for the sensing nodes (C).

dedicated BLE receiver which operates as real-time data collector. Different possible devices can be employed as BLE receivers. A good choice, shown in Fig.2-C, is surely the RaspberryPI Zero: a small computer on single board which features good computing capabilities, very small dimensions (about 65 mm$\times$30 mm), low power consumption and both BLE and WiFi Interfaces. The BLE receiver collects in real time all data coming from the deployed sensing nodes and uploads them to the cloud platform by using the WiFi. After the data have been uploaded to the cloud, they can be accessed remotely from everywhere by the authorized users. Of course, the on-line mode requires an Internet connection always available in the monitored location.

In all the cases where either a real-time monitoring is not required or an Internet connection is not available, the proposed system can work in off-line mode. In such a situation, the nodes operate as stand-alone data loggers storing all measurements in their memory. Users can periodically download the data accessing the monitored location and connecting with the nodes by using any BLE compatible device without any cabling connection. This way it is not required to move the sensing nodes from their position or connecting them to any cable.

3. Discussion and conclusions

The proposed solution satisfies the constraints required for the environmental monitoring in the cultural heritage field. Several other monitoring systems have been developed in last years and made commercially available by different manufacturers. However, few of them have the flexibility of the proposed solution and no one of them can be easily expanded with additional sensors. Typically, manufacturers provides different devices for data logging and real-time monitoring. The proposed solution, instead, can operate in both the modes without any modification choosing automatically the most appropriate mode. Moreover, commercial systems are quite expensive with costs in the order of hundreds USD for each sensor. The proposed sensing nodes, instead, have a cost of about 20 USD for each sensing node and around 10 USD for each BLE receiver. As an example, the temperature and humidity data logger EL-SIE-2+ (Lascar Electronics) [5] has similar measurement performance but an autonomy of only 1 year and quite larger dimensions (93 mm $\times$ 42 mm $\times$ 17 mm). Moreover, it lacks of any wireless interface and, therefore, it is required a cabled data downloading. Another commercial data logger, the 174T (Testo) [6], is able to measure only temperature. It has a battery life of about 500 days, only an USB interface for data downloading and device programming and dimensions of 60 mm $\times$ 38 mm $\times$ $18,5$ mm.

Most of the real-time monitoring solutions that are commercially available are based on a WiFi Interface for connecting the sensing nodes. However, such solutions typically requires a cabled power supply due to the quite high power consumption of WiFi transceivers. As an example, the Saveris 2-H2 (Testo) [7], has a battery life of 12 months or, alternatively, can operate with a cable power supply. It can store only 10000 measurements and it has quite large dimensions (95 mm $\times$ 75 mm $\times$ 30.5 mm).

In conclusion, the proposed distributed monitoring system has very interesting characteristics which are often better than commercial devices, especially in terms of flexibility, expansion capability, battery life and dimensions. Moreover, cost of both sensing nodes and data receivers are much lower than most of the commercial devices. The proposed solution effectiveness has been proved on the field in several monitoring campaigns [8].

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