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Wireless sensor network for indoor and outdoor atmospheric monitoring in culture heritage

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***Abstract* – Environmental monitoring is of paramount importance in the preservation of cultural heritage. Climatic conditions affect significantly the conservation state of cultural heritage assets and can accelerate their degradation process. Thus, a continuous and accurate monitoring system is required in most of the cultural heritage sites to control the micro-climate parameters. The proposed environmental monitoring system complies with the typical constraints required in the cultural heritage field and it is effectively employed in different monitoring campaigns still in progress. The system employs small sensor nodes that measure local temperature and humidity and wireless transmit acquired data to a dedicated receiver. The system is very flexible and can be adapted to serve almost every location, both indoor and outdoor. Moreover, the system can optionally provide a remote real-time data access using a cloud infrastructure when Internet and a power source are available in the heritage site.**

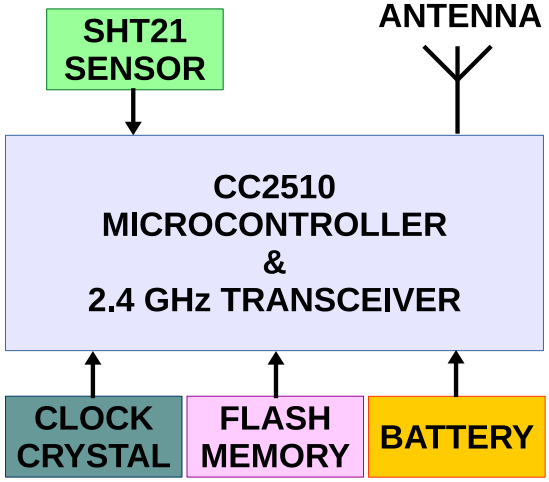

Fig. 1. Simplified block diagram of the proposed sensor node.

I. INTRODUCTION

The conservation state of culture heritage assets (museum artifacts, statues, historical buildings, etc.) can be severely affected by the environmental conditions, as well as by the aggressiveness of indoor and outdoor atmospheres. Thus, a proper monitoring system is almost always required in museums and heritage buildings in order to detect potentially unsafe conditions and to monitor the main climate parameters as temperature and relative humidity, and/or the presence of aggressive gases [1, 2]. Many different monitoring systems have been developed for environmental monitoring measurements [3, 4, 7, 6], not only in the cultural heritage field; however, most of them are usually devoted only to specific applications and present a lack of flexibility. In the cultural heritage field, in particular, the environmental monitoring systems have to satisfy several constraints, such as minimal visual impact on the artifact fruition, long operative life, data quality assurance, easiness and flexibility in the arrangement and maintenance of the monitoring system itself.

Actually the monitoring system is employed in several activities in Italy and abroad. Furthermore, new activities employing the proposed monitoring system have been recently started in Colombia in the frame of a Joint Project for the Internationalization of Research between Italy and Colombia, financially supported by Politecnico di Torino and Compagnia di San Paolo (Torino, Italy) in cooperation with the Antonio Nariño University (Bogotá, Colombia).

II. THE PROPOSED MONITORING SYSTEM

The proposed monitoring system has been designed and developed by the researchers of Politecnico di Torino, taking into account the typical constraints required in the culture heritage field, for both indoor and outdoor applications. It consists in a flexible and easily-configurable wireless sensor network based on small battery-powered sensing nodes.

In the simplified block diagram, shown in fig. 1, the

main components of the measuring nodes are shown:

- The core of the sensing node, that is the system-on-chip CC2510 produced by Texas Instruments. The chip features a low-power microcontroller and a 2.4 GHz wireless transceiver. The firmware running on the microcontroller performs all the operations required for taking and transmitting the measurements.
- The digital sensor SHT21, by Sensirion. This small sensor is responsible for the measurement of both temperature and relative humidity with typical uncertainties of 0.3 °C and 2% RH (from 20% RH to 80% RH), respectively. It communicates with the microcontroller using the I2C interface and it is periodically disabled in order to reduce power consumption.
- The clock crystal, that is used for generating the microcontroller main clock and the transceiver carrier.
- The flash memory, which allows the storage of all measurements acquired by the sensing node. This 4-Mbit non-volatile memory is able to guarantee a permanent backup up to 125000 measurements.
- The lithium battery, that powers the sensing node. The battery capacity can be selected according to the application requirements and is able to power the node for its whole operating life.
- The node antenna, that allows the wireless communication of the nodes. In order to reduce the costs and the size of nodes, the antenna has been implemented with a circular metallic trace tuned at the frequency of 2.4 GHz.

Taking advantage of the good performance of the CC2510 transceiver, the nodes can easily cover a wireless range which goes from 10 m to more than 30 m, according to the environment and the presence of obstacles.

The fig. 2 shows one node prototype enclosed in a custom 3D-printed box, whose size is 25 mm x 16 mm, but a different enclosure (shape, material, color) can be easily designed in order to make the node compatible with different environments, including the outdoor ones, where a rain-proof enclosure is required.

Each sensor node is calibrated before being employed in a monitoring activity: the sensors and a laboratory calibrated probe, both placed in a climatic chamber, are exposed to several temperature and humidity cycles. Measurement data from both the nodes and the probe are collected and a set of calibration data is extracted. Those data can be used to reduce sensor uncertainty when it is employed on-field.

The nodes employ a dedicated proprietary wireless protocol which has been specifically designed in order to reduce power consumption and, at the same time, to provide

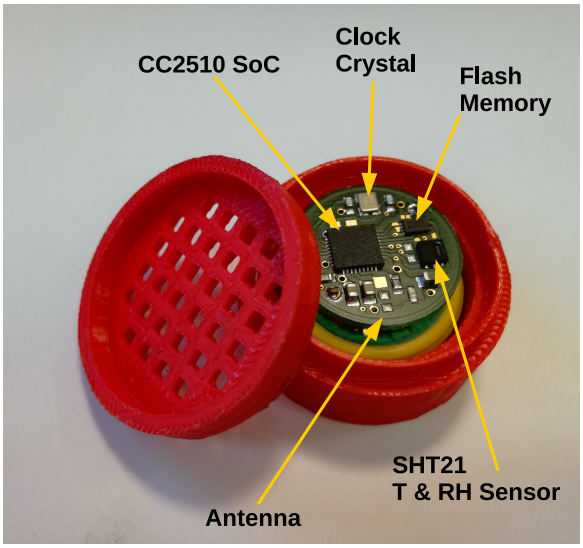

Fig. 2. The node prototype for temperature and relative humidity measurement.

great flexibility in the deployment and management of the monitoring system. Basically, the network is arranged according to the *start topology*, where several wireless nodes communicate with a single receiver. This solution does not provide any inter-node communication, thus more than one receiver could be required to cover large sites. However, considering that the node wireless range (exceeding 10 m) usually allows the complete coverage of an exhibition room and that the receivers are very cheap, it is easy to deploy the network inside museums with very low costs, and with the advantage to improve operative life of the nodes.

After the battery is mounted, the node starts measuring continuously temperature and relative humidity at specified time intervals, which can be selected by the users in the range from 1 s to 3600 s. When a new measurement is ready, the node tries to transmit the data to a dedicated receiver using the provided radio link on the 2.4 GHz band. If the receiver properly receives the data, it responds to the node with an acknowledge package and the data is marked as *received*. Otherwise, the data is marked as *not-received* and it is transmitted again during next trials. Meanwhile, the node stores all the performed measurements in its internal flash memory in order to create a backup copy of all data. This method guarantees that no data can be lost even during critical situations or failures in the network or in the Internet connection.

Moreover, a dedicated cloud architecture is associated to the monitoring system in order to provide remote access to authorized users. The measurement data are pushed to the cloud storage by the receivers in real-time through a secure Internet connection. The cloud is able to organize data in a dedicated database, compensate the sensor uncertainty us-

ing the calibration data, and perform additional data processing according to the application. No measurement is lost, even in case of failure of the Internet connection or power supply. In such cases, data permanently stored in the node memory are retrieved and uploaded in the cloud as soon as possible.

In locations where this approach is not possible (e.g. no Internet connection or power supply), the sensor data downloading can be anyway performed. In such a situation, the user has to periodically go in the monitored site with a USB receiver connected to a laptop for collecting sensor data and manually uploading them to the cloud.

These features have proven to be extremely useful in the employment of the proposed monitoring system in the cultural heritage field making it flexible, accurate and secure against tampering and data loss.

III. THE MONITORING ACTIVITIES

Since the proposed environmental monitoring system fits most of the museum operators and conservators requirements, it has been already successfully employed in several monitoring campaigns in museums and historical buildings both in Italy and Egypt ([5], [8]). The monitoring campaigns here presented, instead, are in progress in two heritage sites in Colombia: the National Museum of Colombia (Bogotà) and the historical site of the *Puente di Boyacá* (Tunja).

A. *Monitoring at the National Museum of Colombia*

The National Museum of Colombia is located in Bogotá and is housed in a historical building used as a prison up to the 1946. The museum hosts a collection of more than 20000 pieces, including pre-Colombian archaeological and ethnographic artifacts, paintings and textiles belonging to different historical periods.

Many artifacts present clear signs of degradation, and the monitoring activity aims to determine if there is a correlation between the conservation state, in particular of the metallic and textile artifacts, and the environmental conditions inside the showcases. With this purpose, six sensor nodes have been placed in different locations inside the museum (showcases and deposits), as explained in the tab. 1. The locations have been selected in order to collect as much information as possible taking into account the different materials composing the artifacts, their conservation state and the type of enclosure they are stored within. Fig. 3 shows the locations where sensor nodes S44 and S45 have been placed.

B. *Monitoring at the Puente de Boyacá*

Puente de Boyacá (the bridge of Boyacá) is a small bridge located in the Boyacá District, 110 km east of Bogotá, crossing Teatinos river. Numerous monuments have been erected in the surroundings to commemorate the historic Battle of Boyacá (August 7^{th}, 1819), which granted the independence of New Granada. The other national monuments and memorials of independence present in the park are a triumphal arch, an obelisk, a flags square, the bronze statues of Francisco de Paula Santander and, on a hill, the Von Miller Monument. The results presented here are from the Von Miller Monument with the bronze statue of Simon Bolivar. The fig. 4 shows the Von Miller Monument and the position where the sensor node S49 has been placed. This position has been chosen to prevent the rain from interfering with the proper node operation.

Table 1. Position of the sensor nodes at National Museum of Colombia, Bogotá, Colombia.

Node ID	Artefact	Room Number
S35	Custodia	Room 13
S38	Pluma de marfil	Room 8
S45	Tumba de pozzo	Room 6
S44	Pizarro's Flag	Texile deposit
S46	Historical guns	Mixed deposit
S47	Alhajas del Perù	Room 15

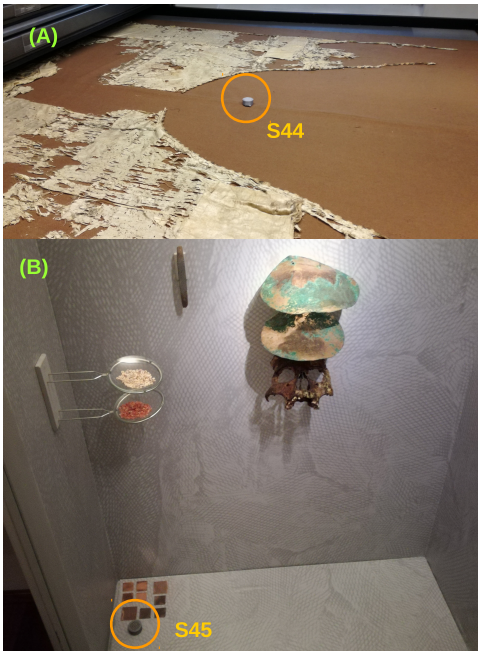

Fig. 3. Placement of the sensor nodes at the National Museum of Colombia (Bogotá): S44 in the Pizarro's Flag drawer, textile deposit (A); S45 in the Tumba de Pozzo showcase, strongbox room 6 (B).

Fig. 4. Placement of the sensor node S49 on the Von Miller Monument (Puente de Boyacá).

IV. RESULTS AND DISCUSSION

The monitoring activity at the National Museum (Bogotá, Colombia) started on July 11^{th}, 2017. The temperature and relative humidity from node S44 (Pizarro's Flag, textile deposit) and node S45 (Tumba de pozzo, strongbox room) have been acquired for more than one month and the results are reported in fig. 5 and fig. 6, respectively. The data clearly show the circadian variation of temperature: excursions along the monitoring period are about 1 °C for both the textile deposit and the strongbox room. In particular, measurements of node S45 demonstrate that when the strongbox room is opened (4 times a week) temperature and humidity exhibit moderate variations; when the room remains closed, the values slowly return to the baseline (19 °C and 65 %RH). Relative humidity is also almost constant with variations which are less than 10 %RH. This is especially true for the textile deposit which remains closed for most of the time. Such environmental conditions can be considered quite safe for the conservation of the artifacts.

The other monitoring activity started on July 7^{th}, 2017 at the *Puente de Boyacá*. The measurement data, acquired by sensor node S49 on the Von Miller Monument (Simon Bolivar statue), are reported in fig. 7. The plots show the outdoor environmental conditions which the monument is exposed to, over a monitoring period of more than two months. The data show very large daily variations of both temperature and relative humidity of about 20 °C and 50 %RH. The environmental conditions are very harsh, being the site at 2800 m above the sea level in a tropical region, and can severely affect the conservation of the bronze statues with the possibility of water condensation.

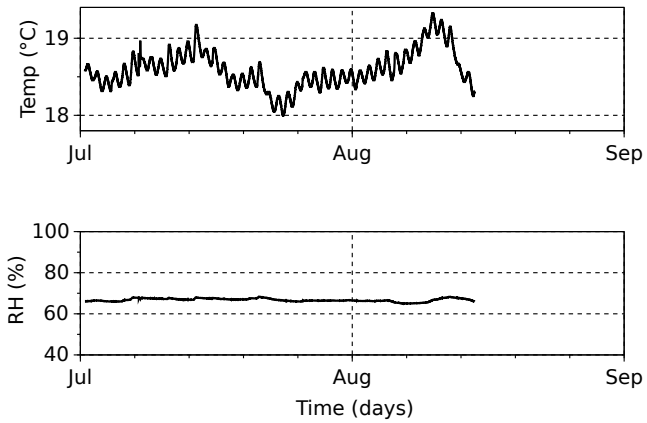

Fig. 5. Temperature and relative humidity collected by the S44 sensor placed in the textile deposit, near the Pizzaro's Flag.

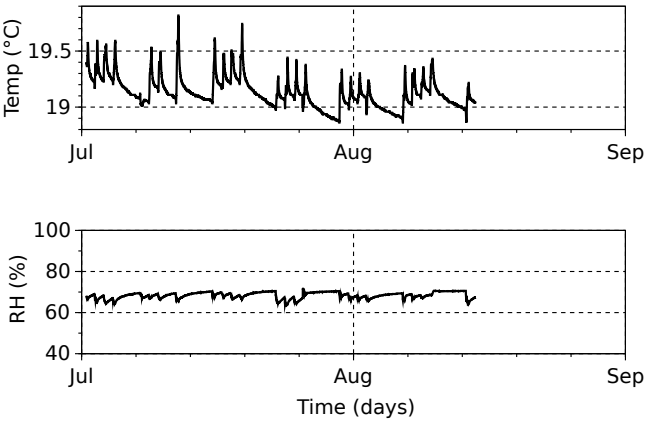

Fig. 6. Temperature and relative humidity collected by the S45 sensor placed in the strongbox room 6, inside the showcase of the Tumba de Pozzo.

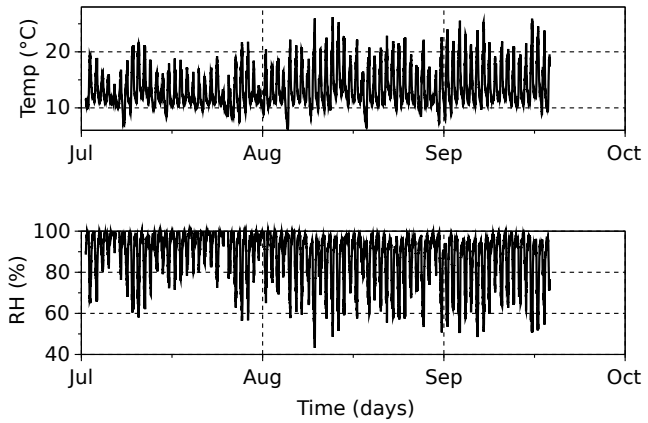

Fig. 7. Temperature and relative humidity collected by the sensor S49 at Puente de Boyacá (Von Miller Monument).

V. CONCLUSIONS

The described systems satisfy the typical requirements for cultural heritage monitoring both indoor and outdoor. They have been very effective in the monitoring activities providing accurate data useful for evaluating the climatic conditions closed to the artifacts. Such information can be used by conservators and curators for improving the artifact conservation and detecting possible unsafe situations. The indoor and outdoor monitoring campaigns are still in progress and new data are continuously collected by the monitoring system in order to better evaluate the environmental conditions along a more extended time period.

VI. ACKNOWLEDGEMENTS

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