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The conservation state of Cultural Heritage (artefacts stored in museums, historical buildings, etc.) can be severely affected by the environmental conditions which they are exposed to. For this reason, a proper monitoring system is typically required in such locations in order to detect potentially unsafe conditions and to monitor the main atmospheric parameters as temperature and relative humidity, and/or the presence of aggressive gases.
In this paper a wireless sensors network, designed and developed at Politecnico di Torino, has been employed for two long-lasting monitoring campaigns in Colombia. The architecture has been deployed both inside museums and outside on historical sites proving its capabilities. The solution is composed of small sensing nodes with volume lower than 8 cm^3 and dimensions of 2.5x1.5 cm, which are capable of acquiring temperature and relative humidity for a time in excess of three years. The nodes are battery operated and communicate wireless to small Arduino-based concentrators connected to the Internet and to a cloud storage. Data from all the nodes are made available on the curator's smart phones in real time, so that the entire site can be monitored from everywhere.
The nodes have the capability of locally storing all the measurements for quality assurance and if either the internet connection is not available or the power supply is missing, the proposed system has the possibility of off-line manually uploading data to the cloud after having transferred them from the nodes to a battery-operated receiver.
The monitoring campaigns, still in progress, are carried out in two historical sites: the National Museum of Colombia in Bogotà and the historical site of the Puente di Boyacá in Tunja.

KEYWORDS: CULTURAL HERITAGE, ENVIRONMENTAL MONITORING, METALLIC ARTEFACTS

INTRODUCTION

The conservation state of cultural heritage (artefacts stored in museums, historical buildings, etc.) can be severely affected by the environmental conditions they are exposed to [1-3]. Thus, a proper monitoring system is required in such locations in order to detect potentially unsafe conditions and to monitor the main atmospheric parameters as temperature and relative humidity, and possibly the presence of aggressive gases which could damage the artefact. This paper describe deployment and use of a wireless sensors network, which has been designed and developed at Politecnico di Torino [4,5, 6]. The system has been employed for two long-lasting monitoring campaigns in Colombia in the frame of an Internationalization Project Italia-Colombia, between the Politecnico di Torino, the Antonio Narino University of Bogotà, and in collaboration with the Colombian Ministry of Culture. To this aim, the authors developed a complete solution which is composed of small sensors and of all the components required to gather and provide the measured data to the final user. The proposed solution is capable of measuring temperature and relative humidity and employs readily available components and can be easily adapted to different areas where a rapid monitoring system deployment and an easy maintenance is required.

The monitoring campaigns, still in progress, are carried out in two historical sites located in Colombia: the National Museum of Colombia (Bogotà) and the historical site of the Puente di Boyacá (Tunja).

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THE MONITORING SYSTEM

Fig. 1 shows the monitoring system tailored to meet the constraints required for Cultural Heritage applications, for both indoor and outdoor.
It consists in a flexible and easily-configurable wireless sensor network based on small battery-powered sensing nodes, able to measure continuously Temperature (T) and Relative Humidity (RH).
The nodes can transmit the data to a dedicated receiver using a wireless radio link working with a proprietary protocol in the 2.4 GHz band. The wireless range is 10 - 30 meters, according to the environment and the presence of obstacles. The dedicated receiver is designed to connect to Internet, so that it is possible to implement a remote data access based on a dedicated cloud infrastructure, when a power supply and an Internet connection are available in the monitored location.

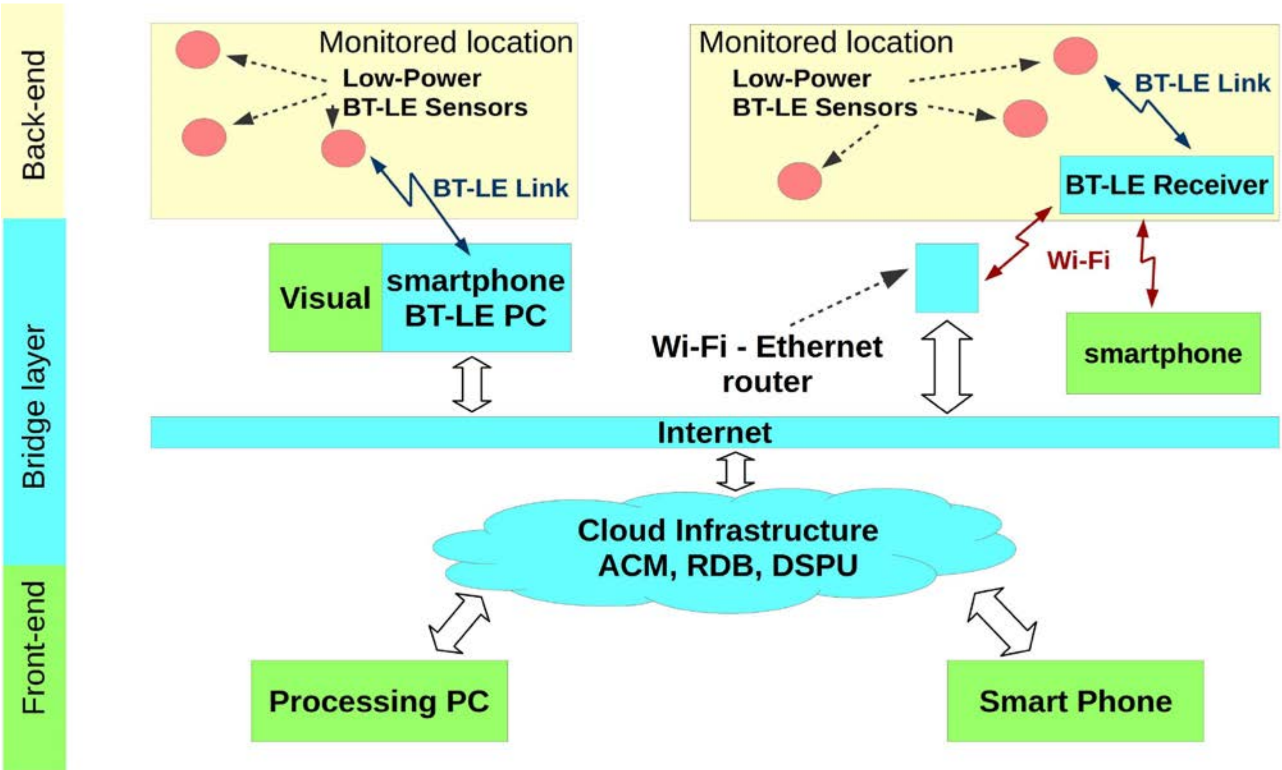
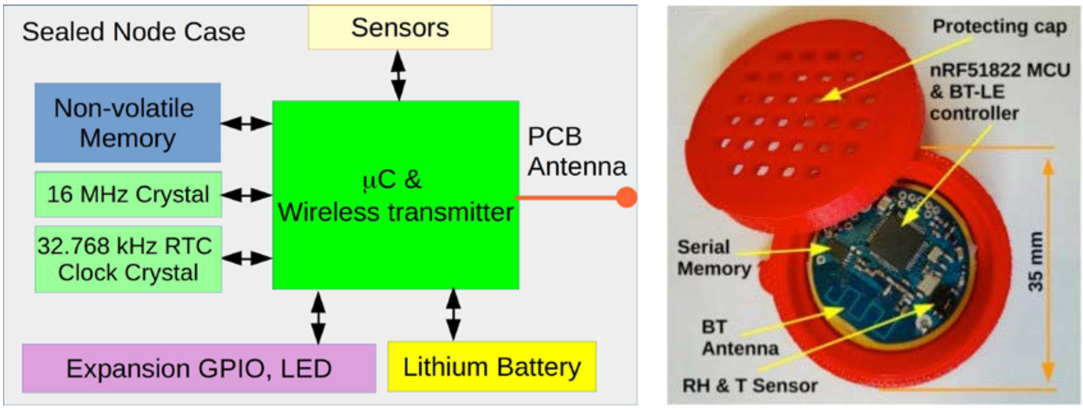


Fig. 1 – Environmental monitoring system 3 layer architecture

The low power consumption of the sensing nodes and the optimization of the transmission protocol allow one to achieve a quite long operative sensor life ranging from 1 to 3 years according to the selected battery and to the sampling rate.
The simplified block diagram of the nodes is shown in Fig. 2, together with the image of a realized prototype. The core of the sensing node is System-on-Chip CC2510 (by Texas Instrument), which features a 8-bits low-power microcontroller and a 2.4 GHz radio transceiver. The firmware running on the microcontroller performs all the operations required for collecting and transmitting the data. A non-volatile flash memory allows an on-board permanent data storage, guaranting a permanent backup of more than 125000 measurements. Temperature and relative humidity are measured by a digital sensor type SHT21 (by Sensirion), which provides an uncertainty of 0.3 °C and 2% for T and RH, respectively. The sensor communicates with the microcontroller using a I2C interface and it is periodically disabled in order to reduce power consumption. The node sampling rate can be selected by the user from 1 s to 3600 s. The clock crystal is used for generating the microcontroller main clock and the transceiver carrier, while an antenna allows the wireless communication. The nodes are battery operated and enclosed in a 3D-printed box (25 x 16 mm), which can be realised in different shape, material and color in order to be compatible and less invasive for the different environments.
Sensor nodes work autonomously without any attendance for all their operative life, storing the data in the non-volatile internal memory. If an on-line receiver is positioned within the operative range of the nodes, they continuously transmit the acquired data and the receiver pushes such data on the cloud using the Internet connection. In locations where this approach is not possible, an USB receiver can be connected to a laptop for periodically downloading the data. These features of the monitoring system have proven to be useful in the Cultural Heritage field, because they make the system flexible, accurate and secure against tampering and data loss.



(a) (b)

Fig. 2 - The simplified block diagram of the sensor node (a), sensor prototype (b)

INDOOR MONITORING CAMPAIGN

The indoor monitoring campaign has been carried out at the National Museum of Colombia. This National Museum is the oldest in the country and one of the oldest in the continent, built in 1823. Its fortress architecture is built in stone and brick; the plant includes arches, domes and columns forming a sort of Greek cross over which 104 prison cells were distributed, with solid wall façade. It was known as the Panóptico and served as a prison until 1946. In 1948 was adapted for National Museum and restored in 1975. The museum hosts a collection of more than 20000 artefacts, pre-Colombian archaeological and ethnographic artefacts, paintings and textiles belonging to different historical periods. Several artefacts are affected by degradation processes, and the monitoring activity aims to determine if there is a correlation between the conservation state, in particular of metallic and textile artefacts, and the environmental conditions inside the showcases.

Six sensor nodes have been placed in different locations inside the museum, showcases and deposits. The locations have been selected taking into account the different materials that constitute the artefacts, their conservation state and the type of enclosure they are stored within.

The monitoring system was deployed in July 2017 and the environmental monitoring activity is still in progress. In order to acquire meaningful information on the indoor environment, Cu-based reference specimens were exposed to the indoor atmosphere inside several showcases. The reference specimens are both as-received or coated with a Cu nanostructured thin film deposited by plasma sputtering, in order to increase their reactivity. This allows one to observe surface degradation phenomena and to analyse them as a function of time.

Fig. 3 shows two of the showcases, under study, with bronze and gold artefacts, where the sensor nodes S35 and S45 have been placed. Sensor S35 is located in room 13, "Custodia", a large room at the first floor. The image inset also shows a details of the Cu coupons. Sensor S45 is located in room 6, Boveda 'El oficio del Orfebre', in the showcase 'Tumba de pozo con camara', an armored room, at the ground floor.

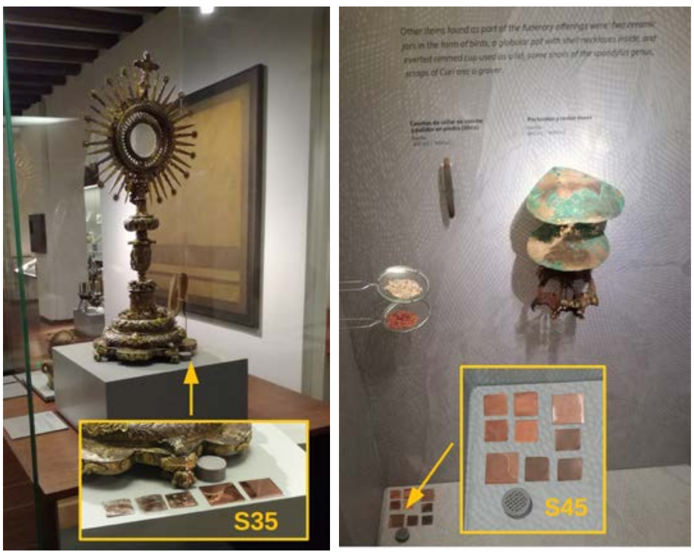
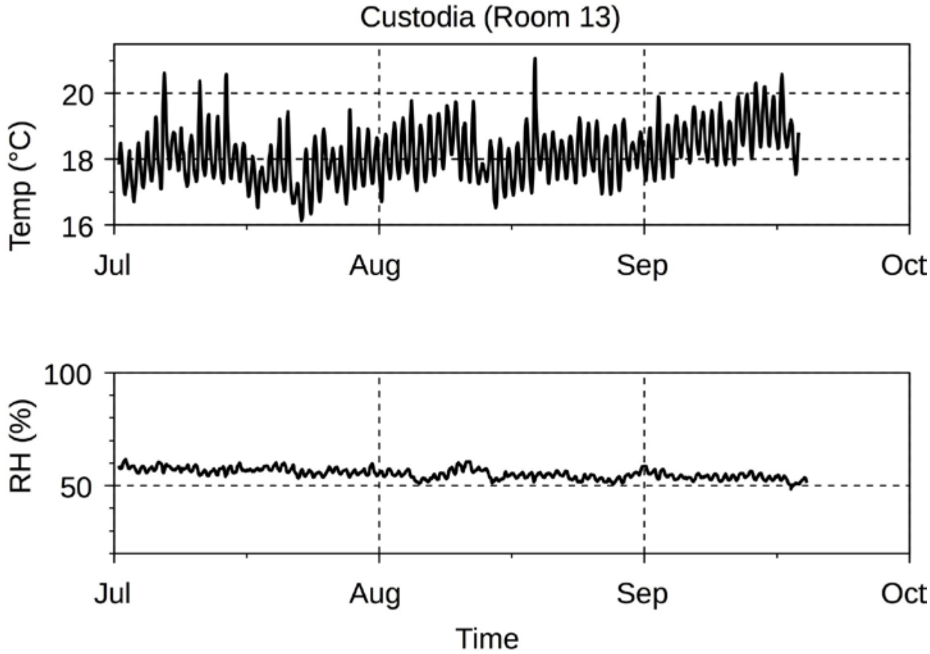
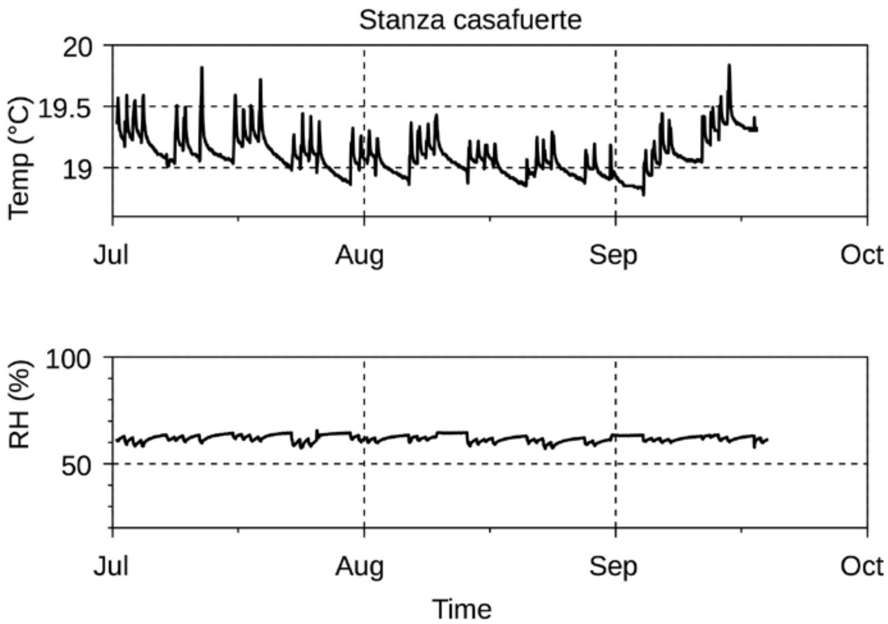
(a)  (b)

Fig. 3 – Sensors and Cu reference samples positioning in the National Museum of Colombia. (a) sensor S35 located in room 13; (b) sensor S45 located in room 6.



(a)



(b)

Fig. 4 – Temperature (T) and Relative Humidity (RH) trends recorded by (a) S35 located in room 13 and (b) S45 located in armored room 6.

In Fig. 4 the temperature and relative humidity data recorded by means of nodes S35 and S45 for more than two months, from July 2017 to half september 2017, are reported.
The experimental findings show clearly the circadian variation of temperature: excursions along the monitoring period are of about two Celsius degrees for room 13 and of less than 1°C for the armored room 6 which has a lower air circulation.
In room 13 the variation of the temperature is from 16 to 21°C, but the variation of relative humidity is negligible and remains around 60%. Data collected from node S45 show that when the armored room 6 is opened, four times a week, T and RH exhibit moderate variations and that, when the room remains closed, the values slowly return to the baseline values, T=19°C, RH 62%. Relative humidity reaches sligtly higher values with respect to the other monitored rooms, due to the fact that the armored room is in the ground floor meanwhile the other monitoring sites are located at the first floor of the building.
Both the environmental conditions may be considered quite safe for the conservation of the artefacts. However the microscopic examination of the surfaces of the copper reference samples highlights a difference in the reactivity of the two-nanostructured copper samples.
Fig. 5 shows the FESEM images of the copper nanostructured specimens after three months of exposure in both the rooms respectively. The morphological analysis highlights the quite safe environmental conditions inside the showcase of room 13.
As a matter of facts, no significant corrosion presence can be observed onto the surface of the Cu nanostructured film, which maintains its well-defined nanostructure.
Meanwhile the relative humidity fluctuations of the showcase in the armored room 6, cannot be considered totally safe for the artefacts conservation, even if the atmosphere is not aggressive enough to induce localized corrosion attacks on the copper reference samples, which can significantly affect the artefacts stability and long-time conservation.
However, due to the higher susceptibility to atmospheric corrosion, the Cu-nanostructured layer shows a localized attack which leads to a coalescence of the copper nanoclusters and a subsequent detachment.
The presence of corrosion attacks, with dimensions of few micrometers, may be attributed to the presence of a slightly higher aggressive air, due to the fact that the armored room si closed most of the time.

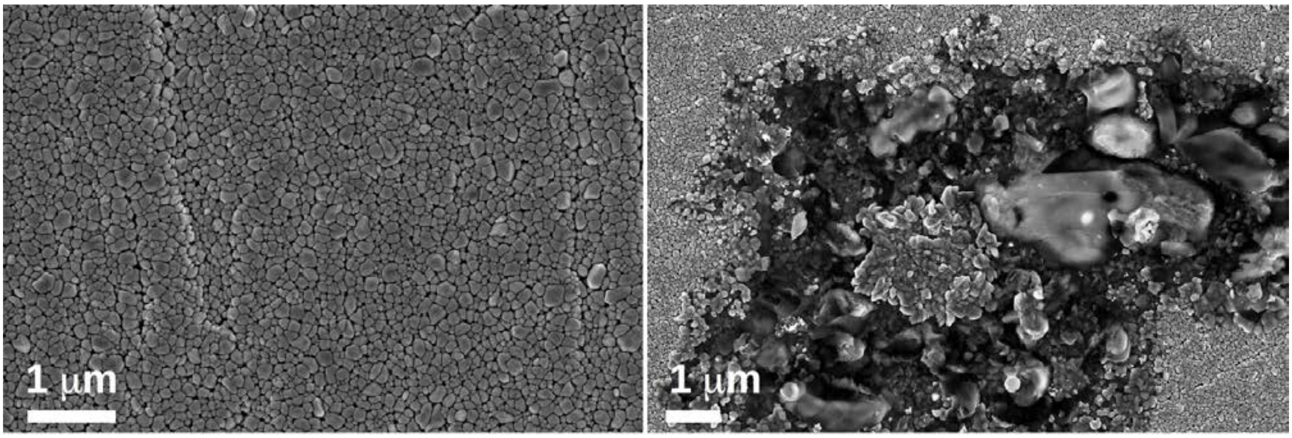


Fig. 5 – FESEM images of the Cu nanostructured reference samples exposed for 3 months close to node S35 located in room 13, and to node S45 located in the armored room 6.

OUTDOOR MONITORING CAMPAIGN

The outdoor monitoring campaign has been carried out at the Campo de Boyacá, also known as Puente de Boyacá, an historical site located at 110 km east of Bogotá, crossing Teatinos river. This site gained a large popularity in Colombia as numerous monuments have been erected in the surroundings of a small bridge (the Puente de Boyacá) to commemorate the historic battle of 7th August 1819, known as the Battle of Boyacá, which granted independence to New Granada.
The bridge was built in the early 18th century, and was dedicated as National Monument and memorial of independence in 1920. The other National Monuments present in the park are a triumphal arch, an obelisk and a flags square. Moreover, the metallic statue of Francisco de Paula Santander, the monument of Pedro Pascasio Martínez and, on the hill, the Von Miller Monument are also part of this important historical site. The Von Miller Monument, shown in Fig. 6, is a bronze monument composed by five allegoric female figures, symbolic of Colombia, Venezuela, Peru, Ecuador and Bolivia, holding Simón Bolívar (1783-1830), the liberator from the Spanish government and the first president of Gran Colombia.
The bronze statues of the Von Miller monument are apparently in a quite good conservation state even if tourists are allowed to climb the monument, risking of removing the surface patina grown on the metal by the interaction with the atmosphere. However, this anthropic damage is less important respect to

the atmospheric conditions the statues are exposed to. Actually, the monument is located at an altitude of about 2800 m and is exposed to a subtropical climate. In this geographical region, temperature remains all over the year in the range 7- 17°C, with an alternation of more or less dry and rainy seasons, but with a high possibility of rain every day. As a matter of facts, the relative humidity can reach 90-100% every day all over the year, leaving the monument exposed to atmospheric corrosion in very aggressive conditions.

Fig. 6 – The Simon Bolivar bronze statue in the Puente de Boyacá, an historical site built in the early 18th century, memorial of independence in 1920.

The monitoring activity started in July 2017 at the Puente de Boyacá. The measurement data, acquired by the node S49 on the Von Miller Monument (Simon Bolivar statue) for more than two months, are reported in Fig. 7. The collected data show very large daily variations of both temperature and relative humidity of about 20°C and 50 %RH. Specifically, the measurements let one to observe how the humidity can get close to 100% during the night with the risk of water condensation on the statues.

These environmental conditions are very harsh, being the site at 2800 m on the sea level in a tropical region, and can severely affect the conservation of the metallic staues maily due to the possibility of repeated water condensation.

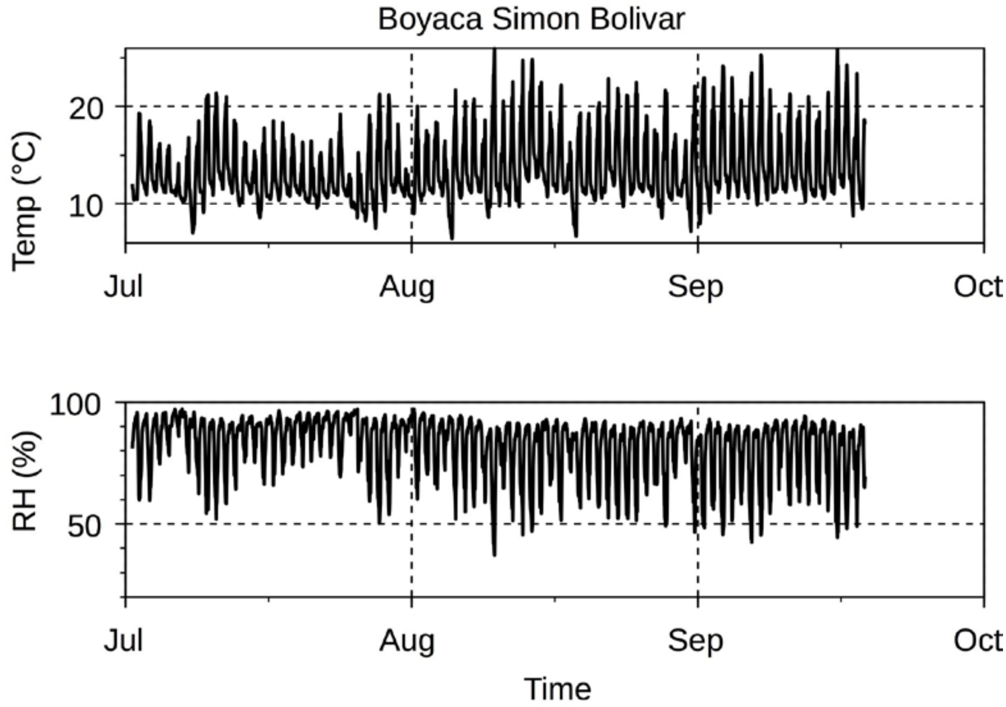


Fig. 7 – Temperature and relative humidity recorded by the sensor S49 at Puente de Boyacá (Von Miller Monument).

CONCLUSIONS

The presented system reveals to satisfy the typical requirements for Cultural Heritage monitoring both indoor and outdoor. It has been very effective in the monitoring activities providing accurate data useful for evaluating the climatic conditions closed to the artefacts.

This information especially if coupled with the deployment of coupon to observe the presence of aggressive componds, can be used by conservators and curators for improving the artifact conservation and detecting possible unsafe situations. The campaign is 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.

Acknowledgements

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