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Cloud Infrastructure for Museum Environmental Monitoring

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***Abstract*—This paper describes a cloud based architecture which has been designed for the monitoring of Cultural Heritage buildings. The architecture has been deployed in museums and basements proving its capabilities. The solution is composed of small sensing nodes with volume lower than $8\ \mathrm{cm}^3$ and dimensions of $2.5\ \mathrm{cm} \times 1.5\ \mathrm{cm}$ which are capable of acquiring temperature and relative humidity for interval in excess of one year. 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 to on the curator's smart phones in real time so that the entire building 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 manually uploading data to the cloud after having transferred them from the nodes to a battery operated PC.**

***Index Terms*—Cultural Heritage, Environmental monitoring, Cloud measuring system**

I. Introduction

The monitoring of the environment inside ancient buildings and or locations where cultural heritages are displayed such as museums is extremely important for a safe management and conservation of both the buildings and of the contained artifacts. Several private and public institutions are actively working on the definition of guidelines and security limits for the different possible pollutants [1], [2]. Specific monitoring infrastructures are required to insure the buildings comply with such limits and commercial monitoring devices appeared on the market to solve the monitoring problems with different cost and performance [3] [4].

However monitoring inside museums requires developer to comply with different constraints, which are specific to the environment. In most cases the displayed artifacts are exposed inside showcases to avoid users to touch them, this implies the environment may be different inside each showcase and in turn this requires a monitoring system capable of obtaining the environment values inside each showcase. In addition, due to the limited dimension of the showcases the sensors must be small and virtually non-invasive to avoid impacting on the artifact fruition. Eventually, the monitoring system must be easy to deploy and to maintain since most curators are not specifically trained either to work with instruments or to be able to manage a complex monitoring architecture.

The authors therefore developed a complete solution composed of sensors and of all the components required to gather and provide the measured data to the final user. The proposed solution employs readily available components and can be easily adapted to different areas where a rapid monitoring system deployment and an easy maintenance is required.

II. The Proposed System Architecture

Many different solutions have been described that can be employed for a distributed monitoring system [5], [6], [7], [8], however most of them are tailored to telecommunications and power applications and do not pay attention to the specific constraints connected to the use in environments like expositions and museums. For these applications the development of a simple low-cost application would be desirable. In this paper the authors describe a solution which takes advantage of the $\mu Panel$ environment [9], [10], which permits a very fast and easy deployment of a measuring system able to cope with all the constraints related to the use in museums.

Fig. 1 shows a simplified block diagram of the proposed architecture, which is based on:

- A set of measuring points capable of sensing the quantities of interest. These points act as the system front-end toward the measured physical quantities. The points are designed with a very low dimension, are powered by a small battery and can transmit data over a wireless connection without any wired cabling. The requirement of a low dimension implies the use of a small battery and, in order to have a long operating life, this turns out in a limited wireless range and in the necessity of transmitting data only at large intervals. The system therefore requires a specific receiver located within the wireless range which is of the order of $10\ \mathrm{m}$
- A set of measurement receivers, usually one per room, that receive data from the measuring points and make them available to the cloud. These data receivers can be of two types depending on the monitoring type. The normal type, which is used whenever both a power supply and an internet connection are available, is designed to

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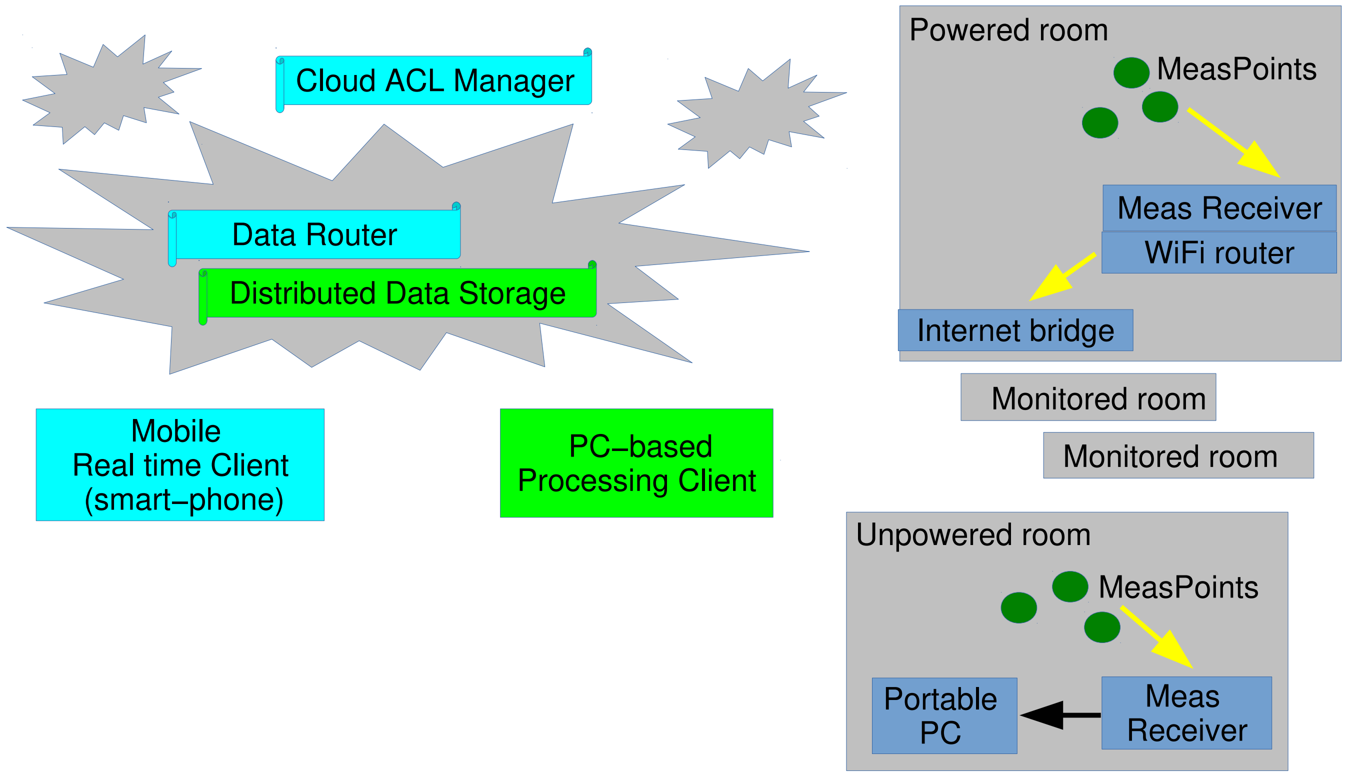

Fig. 1. Block diagram of the proposed architecture.

receive the measurements and immediately route them to the cloud. By using this type of measurement receiver the cloud is updated at regular interval so that the clients, described below can be used for a real time monitoring. If the power supply is not available the normal receivers, that require such power, cannot be used so that a different receiver, designed to be connected to a portable PC is used. This type of receiver is able to gather data from all the measuring points which are within the transmitting range and to send them to the PC. Later, when the PC is returned to a place where internet is available, such data are sent to the cloud and made available to the clients.

- A cloud-based architecture which provides data storage, client data access and user access validation by means of an Access Control List manager.
- The user clients that eventually receive the measurements. The figure highlights the two types of clients, which can be used in this architecture: a) the mobile clients, based on smart-phones which let user to receive in real time the environmental condition as well as alarms, notifications etc.. and b) the Processing clients which are PC-based and which are used for reporting, data processing and estimation and so on.

III. The Measurement Nodes

The measuring nodes are the key points in the architecture as they define the measured quantities and the metrological properties of the entire system. As told in the previous section, the nodes can be in principle designed to measure any kind of quantities even though with different size and dimension.

Fig. 2 shows the simple button architecture designed for the proposed application

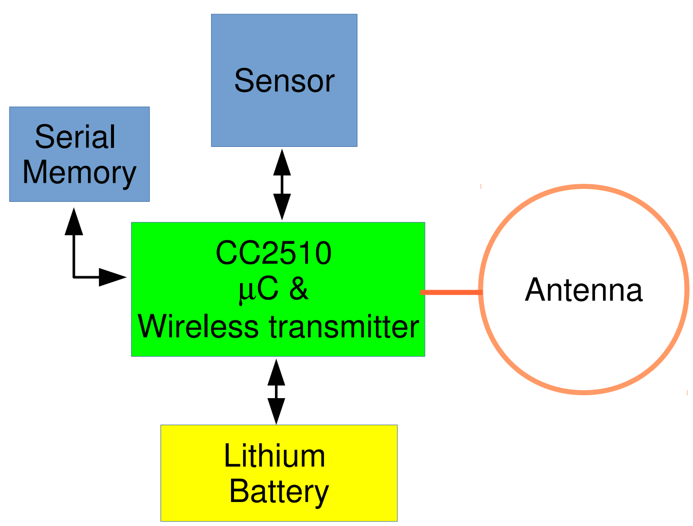

Fig. 2. Block diagram of the sensor node based on the CC2510 μC

The figure shows:

- The node core composed of the CC2510 which is a

compact System On Chip by *Texas Instruments*. This chip is contains the μController which provides the computing capabilities, and the Wireless transmitter.
- The serial memory with size 0.5 Mbyets which provides a non volatile local memory where all the measurements are stored
- The sensor block which can change according to the specific request
- The lithium battery which powers the entire node
- The antenna, connected to the core transmitter, which is used for data exchange with the measurement receiver

This node structure is capable of fulfilling all the constraints are related to size, easy deployment without any cabling and long node useful life.

Fig. 3 shows an example of node prototype designed to measure temperature and relative humidity.

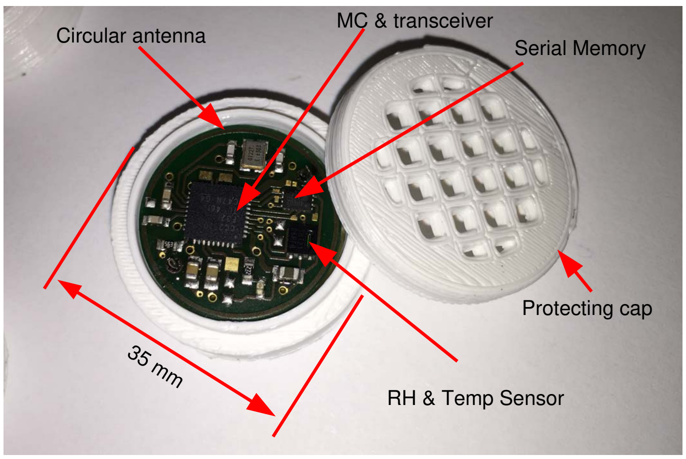

Fig. 3. Picture of one node prototype designed to measure temperature and relative humidity

This prototype employs a lithium battery CR2477 which provides 1 Ah capacity. The prototype employs a Sensirion STH21 as the measuring front end. Such sensor is capable of measuring temperature with a nominal uncertainty of $\pm 0.3°$ and the relative humidity with a typical uncertainty of about $\pm 2\%$ in the range of $20\% RH$ to $80\% RH$. The sensor has a digital output suitable for direct reading form the microcontroller with an amazing resolution of $0.01°$ and $0.04\% RH$ and a typical supply current of about 150 nA during the sleep period.

The microcontroller transmitter is capable of generating a signal of 0 dBm in the ISM frequency band of 2.4 GHz. With these values the connection range varies between 10 m and 30 m [11] depending on the presence of concrete obstacles. The entire node is contained inside an ABS box which is created by using a 3D printer. The cap is designed to let the air freely enter the box so that both humidity and temperature can be measured. The box has a diameter of about 35 mm and a thickness of about 20 mm.

Each node is identified with a unique ID encoded inside the firmware which is used to uniquely identify the node and can be associated to a sensor transducer electronic data sheet (TEDS). Due to the limited amount of memory inside the CC2510, the TEDS cannot be stored inside the node, but can be easily maintained on the Cloud ACL Manager, that is designed to maintain a list of all nodes. Each node can be easily calibrated inserting it inside a climatic chamber along with a reference sensor. This permits to trace the measurements to the relevant standards and to ensure the measurement quality by checking the nodes on return from the measuring site. The local non-volatile memory installed on the node retains all the measurements which can be read at any time for quality assurance.

By using the described battery, and by keeping the microcontroller in deep-sleep mode for most of the time, it is possible to achieve extremely long sensor life. An an example, if the node is programmed to awaken every 30 min to read temperature and humidity, store the results in the local memory and send them to the receiver, the node life can be estimated in more than three years. If a shorter node life can be tolerated, the lithium battery can be replaced with one having lower power storage with the advantage of a lower size. As an example, by using a CR2032 battery, which has a capacity of 225 mAh, the useful life can be estimated in about one year, with the advantage of a node size reduced to about 25 mm $\times$ 15 mm. The local memory has space for more than three years of data and this permits to plan in advance a maintenance cycle of three years.

When the nodes awake, the radio transmitter is turned on and the nodes broadcast a message trying to connect to a receiver. If any receiver is within the transmitting range, it answers the request and the node sends to the receiver all the measurements never sent to it. After all the measurements are successfully received by the receiver, an acknowledge message is sent to the node, that avoids sending the data again. If either no receiver engage the transmission on the acknowledge is not received the node data are marked.

IV. The receivers

As shown in fig. 1, the proposed architecture employs two different receiver types depending on the availability of power supply. As told before, when the nodes awake, they try to contact a receiver, thus the receiver must be on all the time in order to listen to the node requests. This requires the availability of a power supply source. If the mains is not available, a receiver can be designed that gets power from a PC.

A. *Receiver for on-line monitoring*

When the room to be monitored is equipped with power supply and there is an Ethernet WiFi signal, the proposed architecture can be implemented to allow a continuous on-line monitoring. In this case

Fig. 4 shows an example of receiver prototype designed for on-line monitoring.

The receiver is based on three main components:

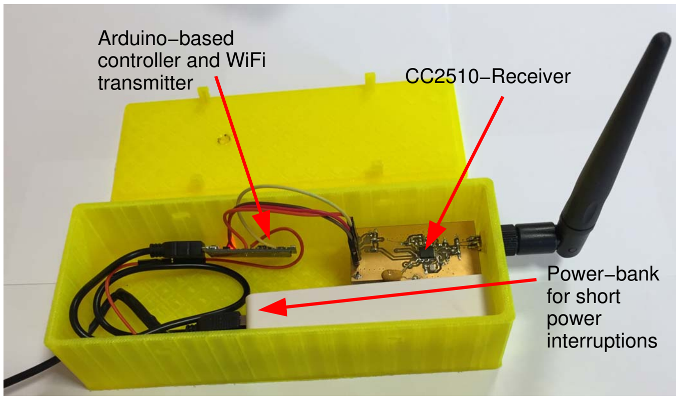

Fig. 4. Picture of a prototype receiver designed for on-line monitoring in the presence of power supply

Fig. 5. Picture of a prototype receiver designed to be powered by the USB port of a PC

- The actual data receiver, which listen for node requests and is arranged by using the same CC2510 $\mu Controller$ used in the nodes. In the receiver implementation the microcontroller is powered by the mains powered and its firmware never puts it in sleep mode. This way the controller reacts immediately as soon as a nodes tries to connect. After the connection the firmware manage the data transmission from the nodes, routes the measurements to the Arduino board and acknowledges the data receive when everything has been sent to the Ardunio board.
- The Arduino-based controller board deals with the management of the received measurements and controls the ESP8266 WiFi chip which interfaces the receiver to the internet. In order to speed-up the WiFi development, the firmware for the ESP8266 is obtained taking advantage of the $\mu Panel$ infrastructure whose firmware is downloaded inside the ESP8266 chip. The $\mu Panel$ code takes care of the rceiver registration into the internet and of the data transfer to the cloud. In addition, the $\mu Panel$ firmware takes advantage of the ESP8266 memory to provide a virtual disk where about 16.000 measurements can be stored in case the Internet connection is temporarily unavailable. This way it is possible to obtain in a simple way not only the data transfer to the internet, but also to create with few lines of code also the virtual App aspect which is used by the smart-phone clients. Based on the $\mu Panel$ specifications, the Arduino controller defines the aspect of the graphical panels (i.e. the virtual App), receives the user notifications regarding the panels' control objects, and sends to the users push notifications to report alarms and abnormal conditions. All these functions are implemented by the $\mu Panel$ code, while the code running on the Arduino controller needs to focus only on the specific measurement system.
- A power-bank which is designed to power the receiver for few hours in the case the mains power supply is shortly missing for some reasons. Using this power-bank and thanks to the $\mu Panel$ virtual disk the system can monitor the mode data even though the internet connection is not always active and/or in the presence of mains interruptions.

B. Receiver for off-line mode

Fig. 5 shows an example of prototype of receiver designed to be connected to a PC. In this case the receiver employs the PC USB port to get the power and to transmit the data.

The off-line mode receiver is composed of two main blocks:

- The actual data receiver, which is the same as the receive already described for the on-line receiver. In the off-line receiver implementation the microcontroller is powered by the USB and also in this case the firmware never puts it in sleep mode. This way it is possible to react immediately as soon as a nodes tries to connect and to receive the data as soon as the node awake. All data are sent to the PC and stored in its memory to be uploaded to the cloud.
- A USB PC interface which is obtained through an Arduino-based controller board. In the off-line receiver there is no need to employ the $\mu Panel$ firmware since the measured data are not immediately fed to the cloud and therefore the receiver needs not to be interfaced to the internet and needs not to provide the continuous panels for the smart-phone clients.

The use of the off-line receiver requires the user to occasionally go to the unpowered monitored room with a portable PC and the receiver and to turn it on by connecting it to a PC USB. This way the receiver starts listening for nodes and as soon as they awake downloads their data. The download session therefore simply requires to wait until all nodes awake i.e. a time of about one awake interval. After all data are downloaded the PC can be taken to any office, connected to the Internet and the acquired data sent to the cloud where they can be browsed by the processing clients.

Since the nodes have their memory and store data without limitation with the exception of the battery duration, the download operation can be performed at arbitrary long intervals, i.e. when for some reason it is necessary to access the not powered room.

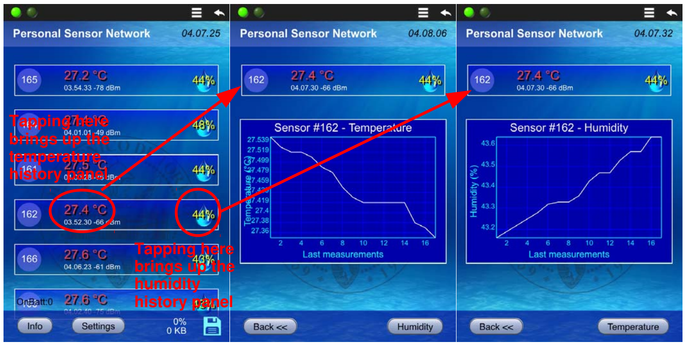

Fig. 6. Pictures of the virtual panel arranged on a smart-phone by using the $\mu Panel$ technology and which is generated by the on-line receiver

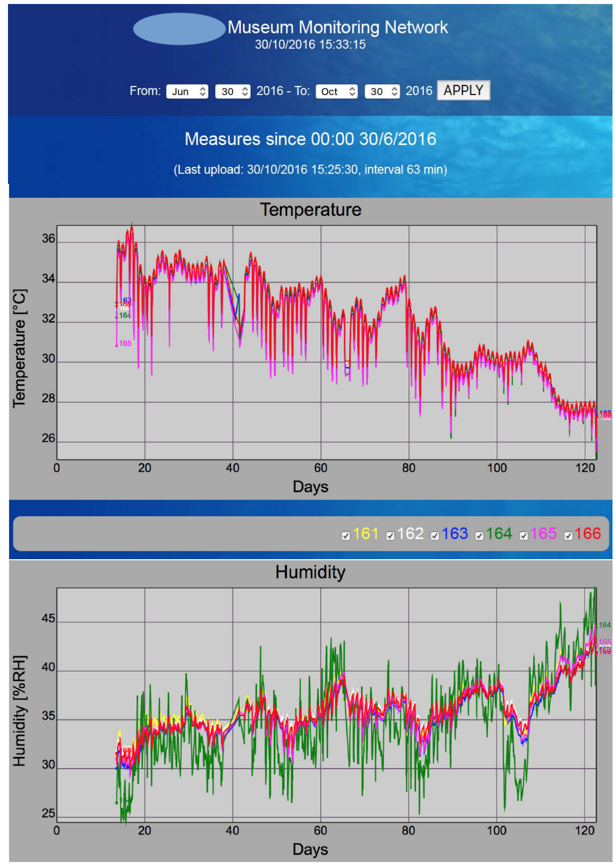

Fig. 7. Pictures of the virtual panel arranged on a smart-phone by using the $\mu Panel$ technology and which is generated by the on-line receiver

V. The Real Time Client

Having tooks advantage of the $\mu Panel$ architecture, the real time clients are automatically available on any smart-phone for which the $\mu Panel$ App is available. This includes iPhones and Android based smart-phones. For these phones the only required operation is to download the App from the relevant store and to activate it. After this the phone can be activated either by putting it in near to the modules connecting it directly to the nodes or by having the network administrator to insert their code into the ACL. After this operation the App, which connects to the cloud downloads the last measurements from the nodes, if they are connected to the internet: the virtual panel is automatically provided by the code generated by the $\mu Panel$ receiver, which sends it to the smart-phone via a small data packet encoded in *HCTML* (Hyper Compact Text Markup Language). As an example fig. 6 shows the virtual panel for some nodes located inside a powered and monitored room located in one of the monitored Museums.

All these sections can be obtained by sending on the virtual panel a string of less than 0.5 kByte. The panels have sensitive points to get some additional details. As an example by tapping over the temperature (or humidity) value of one sensor the user can receive the history of the last two days of the requested quantity.

VI. The Off-line Client

The off line client simply requires a connection to the cloud and a valid account to download data from the server. Two possibilities are available for data downloading. In the simplest arrangement data from a selected time interval can be viewed simply by using a browser.

Fig. 7 shows as an example this kind of visualization, which is obtained by using the browser. The picture displays temperature and relative humidity recorded over a time interval of 4 months in one of the monitored museums. The screen-shot clearly shows the circadian cycles which, involve temperature changes of $2°$ to $6°$, and humidity changes of up to $10\%RH$. As the temperature decreases from summer to fall, the humidity increases still remaining at safe levels. One of the traces, characterized by the green colour, shows a remarkable higher humidity change.

Such changes can be analysed either by asking data on a shorter period of time or by using a client capable of asking the cloud the raw data. In fact, all data can be obtained by a client capable of querying the database so that it is possible either to highlight any abnormal behaviour or to verify what happened in a specific date and time. As an example, fig. 8 shows an expansion of the previous data over five days located as start of October. In this expansion the humidity changes related to the green line can be easily analysed. In the example this trace refers to a sensing node located in the monitored room, but outside the showcases: the humidity has a large change at museum opening when the windows are opened to change the inner air. All the other nodes, related to points inside the showcases show a only a very small humidity change, which remains below $40\%RH$ and thus in at a safe value.

VII. Conclusions

The problem of local environmental monitoring is becoming more and more important not only for normal houses and for a comfortable environment, but also inside museums as well as inside other buildings used to store and display ancient artifacts. In such cases in addition to the normal constraints

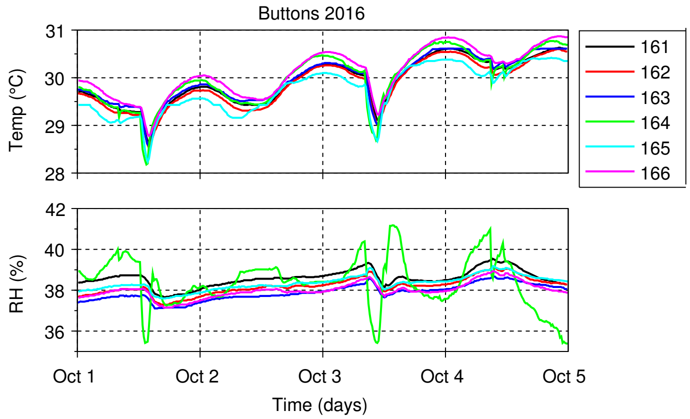

Fig. 8. Example of Temperature measurements obtained over five days by six sensors located in different points of a single room. The green line refers to a sensor located outside thr shwcases

related to the measurement accuracy other limitation applies mainly due to the very nature of the historical artefacts. In these cases the measuring systems have to be nearly invisible to avoid impairing the artifact fruition by the users and often no cabling can be deployed in heritage buildings that must be preserved.

This paper describes a versatile architecture based on small measuring points with dimension of few centimetres that do not require either power supply or cabling and that connects to small concentrators with a wireless connection. The nodes can be calibrated and can be installed by non trained operators close to the points to be monitored, have a life time of about three years and need not maintenance during this period. Data from these nodes can be obtained either continuously for an on-line monitoring when the location has both electric power and internet connection or can be collected at random interval when the power is not available. This permits to monitor also locations like basements and storage site where a continuous human presence is not possible.

The paper describes a specific realization designed to measure temperature and relative humidity, but the proposed solution can be easily extended to add low-power GAS sensors. The architecture provides a distribute storage based on a cloud paradigm which can be queried either by a specific App on designated smart-phones or by means of any PC.

References

[1] C. M. Grzywacz, "Monitoring for Gaseous Pollutants in Museum Environments", The Getty Conservation Institute, 2006, available at http://www.getty.edu/conservation/publications_resources/pdf_publications/pdf/monitoring.pdf, last checked 2015, Sept. 20.

[2] D. Camuffo et. al, "Environmental monitoring in four European museums", Atmospheric Environment, Vol.35, supp.1, 2001, pp. S127-S140

[3] National Park Service: "Comparing Temperature and Relative Humidity Dataloggers for Museum Monitoring" Conserve O Gram Series, N.3/3 Sept. 2011, avaliable at http://www.nps.gov/museum/publications/conserveogram/03-03.pdf, last checked 2015,Sept. 20

[4] Testo Saveris - Available at https://www.testo.com/en-US /Target-groups /Industry/Industry—Museums-and-Archives /c/target _groups_industry _museums _archives last checked 2016, Oct. 25

[5] G. Zhongwen, et al,"IMA: An Integrated Monitoring Architecture With Sensor Networks", IEEE Tr. on Instrumentation and Measurement, vol. 61, no.5 pp. 1287-1295, 2012

[6] J. Schmalzel; F. Figueroa; J. Morris; S. Mandayam; R. Polikar, "An architecture for intelligent systems based on smart sensors", IEEE Tr. on Instrumentation and Measurement, vol. 54, no. 4, pp. 1612-1616, 2005

[7] A. Carullo; S. Corbellini; F. Ferraris; M. Parvis; A. Vallan, "Integration of low computational power nodes in a GRID measurement architecture", IEEE Instrumentation and Measurement Technology Conference IMTC 2007, pp. 1-5, 2007

[8] B. Gedik; L. Liu, "A scalable peer-to-peer architecture for distributed information monitoring applications", IEEE Tr. on Computers, vol. 54, no. 6, pp. 767-782, 2005

[9] The $\mu Panel$ system. Available at http://www.miupanel.com, last checked 2016, July. 26.

[10] S. Corbellini, M. Parvis "Wireless Sensor Network Architecture for Remote Non-invasive Museum Monitoring", Proceedings of the 2016 International Symposium on System Engineering ISSE 2016, Edinburgh, UK, Oct. 3-5, 2016, pp. 34-40

[11] S. Corbellini; F. Ferraris; M. Parvis, "A system for monitoring workers' safety in an unhealthy environment by means of wearable sensors", IEEE Instrumentation and Measurement Technology Conference IMTC 2008, pp. 951-955, 2008

[12] S. Corbellini; M. Parvis; S. Grassini; L. Benussi; S. Bianco; S. Colafranceschi; D. Piccolo; "Modified POF sensor for gaseous hydrogen fluoride monitoring in the presence of ionizing radiations", IEEE Transactions on Instrumentation and Measurement, Vol. 61, Issue 5, 2012, pp. 1201-1208.

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