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IoT-MHECHA: A new IoT architecture for Monitoring Health and Environmental parameters in Cultural Heritage and Archaeological sites.

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Abstract – **In this paper we propose a new Internet of Things architecture for health and environmental monitoring of cultural heritage sites. The proposed architecture supports a broad range of sensor nodes and wireless technologies and thus can be profitably used in several application scenarios related to the management of cultural heritage sites, from microclimate and structural monitoring to security and surveillance applications and even for multimedia content distribution. In particular, the architecture supports the LoRa protocol so that it can be used even in outdoor scenarios such as historical buildings and archaeological sites. Finally, the software used to implement the architecture is open source and readily available so that the architecture can be easily replicated and extended.**

I. INTRODUCTION

The pursuing of the conservation of cultural heritage, understood as architecture but also as mobile finds, means ensuring the best conditions of conservation and usability of the artworks themselves. The degradation of artworks and artifacts in museums and archaeological sites is mostly due to their exposition to human factors and environmental and climatic variations. Therefore for artwork conservation it is very important to monitor environmental parameters (temperature, relative humidity and light intensity), as well as vibrations and deformation, and, also, pollutants (carbon dioxide, acids, etc.). Not too many years ago, environmental parameters and pollutants were measured in cultural heritage sites using costly and bulky measurement systems, such as psychrometers and ultraviolet analyzers, with not negligible problems. In fact, such as measurement equipment need for specialized technicians, have not negligible visual impact and in most cases can not provide continuous measurements. Nowadays, with the introduction of Wireless Sensor Networks (WSNs) and the Internet of Things (IoT) paradigm, most of the above problems can be solved. A WSN is composed by a large number of small-size electronic devices, referred to as sensor nodes or motes, able to measure physical parameters of their surrounding environment and to communicate each other by means of wireless communication interfaces [1].

By using motes with appropriate sensing and communication technologies, it is possible to carry out a diversified series of activities with the double purpose to highlight critical dangerous situations for artworks or for the conservation of the property itself, and to monitor and enhance the relationships between any cyclical events and data collected in a given period of time [2, 3, 4].

In this paper, we exploit WSN and IoT technologies in order to define a new architecture for health and environmental monitoring of cultural heritage sites. In particular, the proposed architecture can be profitably used for both indoor and outdoor environments, e.g. museums and archaeological sites, and can be adapted to several application scenarios, from microclimate and structural monitoring to security and surveillance applications and even for multimedia content distribution.

The advantages of the proposed architecture in comparison to state-of-the-art solutions can be summarized as follow:

- it supports a broad range of sensors, from simple temperature and humidity sensors to gas and sound sensors. This large number of available sensors enables a broad range of applications.
- it integrates several wireless technologies, i.e. ZigBee, Bluetooth, WiFi and LoRa. In particular, the LoRa protocol enables long-range communications (up to tens of kilometers) which is an essential feature for monitoring archaeological sites.
- the software used to implement the architecture is open source and readily available. Therefore the architecture can be easily replicated and extended.

II. RELATED WORKS

In Tab. 1 we summarized a few state-of-the-art solutions for monitoring and control of cultural heritage sites. In particular, for each solution we highlighted available sensors, wireless technologies and target applications.

As it is possible to observe, several works proposed limited solutions mainly focused on indoor temperature (T), humidity (H) and light (L) measurements. In a few cases, pressure (P), vibrations (V) and gaseous pollutants (G) are measured too. A very few solutions provides actuators (A),

Table 1. A few WSN- and IoT-based monitoring solutions for cultural heritage.

Ref.	Sensors/ Actuators	Wireless Tech.	Applications
[5]	T,H,P, G,V	802.15.4/ ZigBee	Monitoring (microclim., pollutant and structural)
[6]	T,H,L, G,V,A	ZigBee	Monitoring (microclim.), Surveillance, Light contr.
[7]	T,H,L, V,A	WiFi	Monitoring (microclim.), Surveillance, Light/HVAC control
[8]	T,H,L	GFSK	Monitoring (microclim.)
[9]	–	WiFi+BT+ ZigBee	Interactive environment
[10]	T,L,V	802.15.4	Monitoring (microclim.), Surveillance, Smart env.
[11]	T,H,L	ZigBee	Monitoring (microclim.)
[12]	T,H,L,V	802.15.4	Monitoring (microclim.), Surveillance, Smart env.
This work	T,H,L,P, V,G,S,A	802.15.4+ WiFi+BT+ LoRa	Monitoring (microclim,, pollutants and structural), Smart env., Surveillance, energy management

mostly based on simple relays and switches used to drive on/off control systems and light dimmers.

The proposed solution integrate all the above sensors together with small-size microphones able to monitor acoustic vibrations (S).

As regards wireless technologies, almost all the solutions rely on IEEE802.15.4/ZigBee. However in a few cases WiFi and Bluetooth interfaces are exploited. As general rule, ZigBee is preferred for reducing energy consumption. On the other hand, WiFi and Bluetooth simplify communications between sensor networks and mobile devices. In particular WiFi is mandatory to deliver context-aware services to the visitors.

The proposed solution integrates all the above wireless technologies. Moreover, it supports the LoRa protocol, which enables long range communications (up to tens of kilometers). Using LoRa it is possible to have a control room several kilometers far from the sensor field, as usual in archaeological sites.

As regards the applications, available solutions can be broadly classified into five categories: environmental monitoring (micro-climate and/or pollutant), structural monitoring, interactive/smart environments, security/surveillance and control applications (usually suited for energy management, e.g. HVAC and light control).

The proposed architecture has been thought to be highly modular and flexible so that it can be profitably used in all the above application scenarios. Moreover we are considering to extend the application layer with the aim to include machine learning algorithms for energy forecasting.

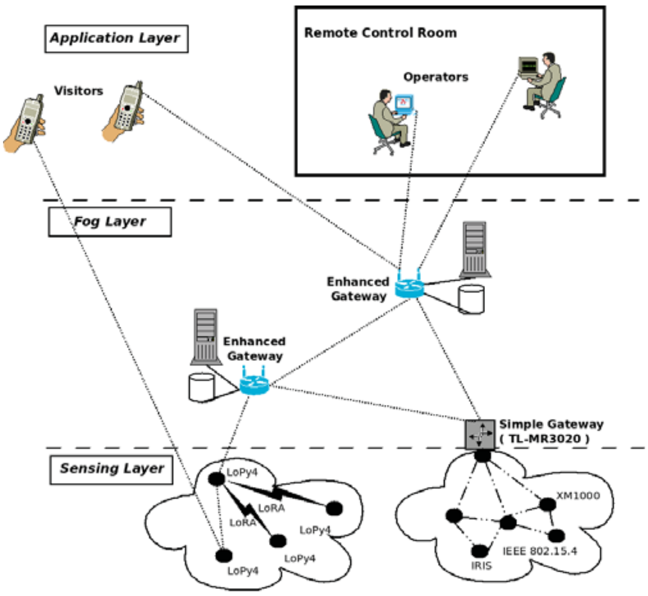


Fig. 1. IoT-MHECA Architecture.

III. IOT-MHECHA ARCHITECTURE

Proposed architecture is shown in Fig. 1 and consists of three layers, named sensing, fog and application layer, which are described below.

A. *Sensing Layer*

The *Sensing layer* consists in sensor nodes and their sensor boards. Three sensor boards and four kind of sensor nodes have been integrated for the proposed architecture (see Fig. 2) which combined can cover all possible application scenarios discussed in the previous section:

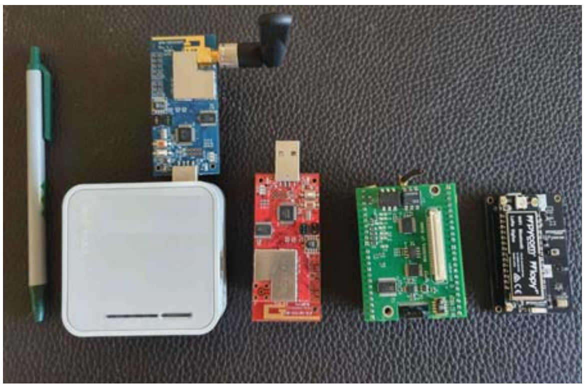


Fig. 2. Motes used for IoT-MHECHA (from left to right): CM5000 (connected to the gateway), XM1000, IRIS (with MDA300CA), LoPy4 (on top of PySense).

- MDA300CA [13]: this board includes temperature and humidity sensors, 11 ADC channels, 2 relay channels, a 64K EEPROM for calibration data, an I2C interface. This board is mainly used to interface gas sensors and for control applications.

- MTS310CA [13]: this board includes light, temperature, accelerometer, magnetometer and sound sensors. This board is mainly used for vibration analysis. Note that differently from all previous solutions, the proposed one is able to monitor both mechanical and acoustic vibrations.

- PySense [14]: this board contains ambient light, pressure and humidity sensors, a barometric pressure sensor and a 3-axis 12-bit accelerometer with an ultra low-power operation in deep sleep mode (near 1μA).

- LoPy4 [14]: this mote support WiFi, Bluetooth and LoRa protocols. It can be used in combination with PySense board for long range environmental monitoring and surveillance applications. Moreover, WiFi and Bluetooth protocols can be used for delivering context-aware services to visitors by means of their portable devices, e.g. smartphones and tablets.

- CM5000 [15]: is an IEEE 802.15.4 compliant wireless sensor node similar to the well-known "TelosB" but with a higher transmission range thanks to an external antenna with 5dBi directivity gain. We used this node as Sink/Base Station for all the other nodes based on IEEE 802.15.4 protocol.

- XM1000 [15]: is similar to CM5000 but with upgraded 116KB program flash. Therefore it can be used when more complex applications or protocols must be implemented. This mote integrates temperature, humidity and light sensors and provides DAC, ADC and I2C interfaces so that other sensors and actuators can be easily interfaced.

- IRIS [16]: an IEEE 802.15.4 compliant wireless sensor node used in combination with MDA300CA or MTS310CA sensor boards for sensing and control applications.

Note that all motes have very small dimensions (8x3x2cm or less) so they can be placed even near artworks with a very limited visual impact (see Fig. 6).

B. Fog Layer

The *Fog layer* is composed by one or more gateways which collect data from sensor nodes and forwards them to a remote control room (or to external Cloud services, when needed). To implement the gateways we considered two different solutions with different trade-offs between costs and computational resources:

Fig. 3. Siesta- Paul Gauguin, oil painting reproduction by M. Campobello, private gallery (mote placed on top-right corner).

- The first solution is based on a low-cost TP-Link router (TL-MR3020) where OpenWRT (chaos calmer version) has been installed. This router can operate as a WiFi hot-spot or even as a WiFi repeater to extend coverage. As shown in Fig. 2, the router is connected to a CM5000 sensor node so that it realizes a bridge between WiFi devices and 802.15.4 sensor nodes. It is worth noting that this is a very compact system with linear dimension similar to that of a stylus pen. This gateway redirect all the traffic coming from sensor nodes to the remote control room.

- At the time of writing, we are implementing a more complex gateway based on a Arduino-like board, referred to as Enhanced Gateway, able to integrate more complex signal processing techniques and control algorithms, i.e. data aggregation algorithms [17] and PID controls [18].

C. Application Layer

The *Application layer* consists in a graphic user interface for network management (NM-GUI) to be installed in a server of the control room and an App, able to provide services to both visitors and operators, and that can be installed in both Android and Apple mobile phones.

The NM-GUI used for network management is shown in Fig. 4 and has been developed starting from Octopus [19], an open source software that allows the user to control the behavior of sensor nodes. In particular, Octopus is able to show sensor network topology and enable remote configuration of sensor node parameters, such as sampling period and duty-cycle of the radio interface.

We customized and extended Octopus with new functionalities suited for monitoring of cultural heritage sites. In particular, we extended Octopus to support different

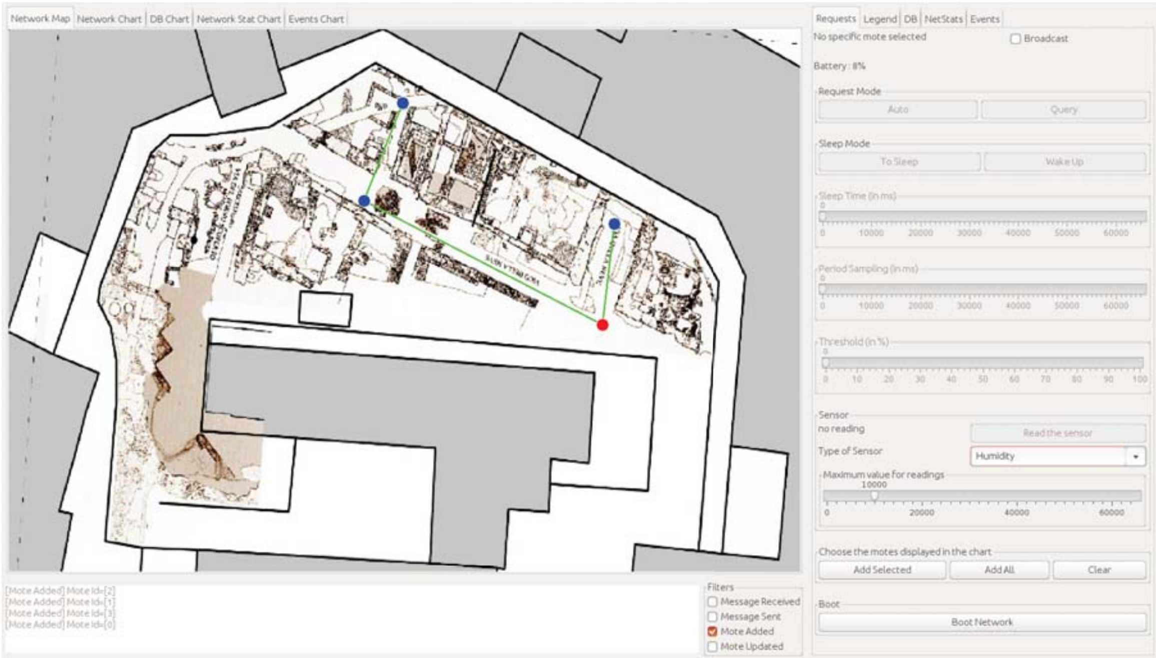
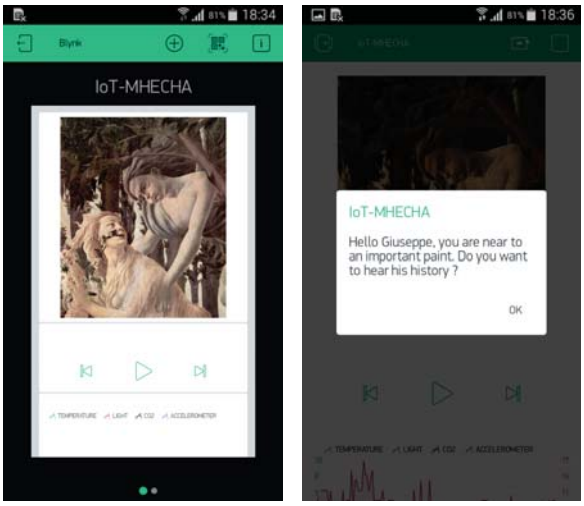


Fig. 4. NM-GUI based on Octopus.

kind of sensor nodes (IRIS, XM1000 and CM5000 have been tested and extend the list of originally supported motes, i.e. MicaZ, Mica2, Telos). Moreover, we modified the packet structure so that with a single packet it is possible to send multiple readings coming from different sensors, i.e. nodes with multiple sensors are now supported. The battery voltage of sensor nodes is measured too and an alert is sent when it is below a pre-configured threshold. Originally Octopus has been developed to provide live data plots. Therefore we interfaced Octopus with a MySQL database so that sensor readings can be analyzed at any time with the aim to extract useful statistics.

Each sensor node can be configured in Time-driven, Event-driven, or Query-driven mode. Desired configuration and related parameters can be set by means of the NM-GUI. In Time-driven mode, nodes send packets periodically at regular time intervals (Sampling Period). This modality is mainly used for monitoring applications. In the Event-driven mode, nodes send packets when a pre-configured threshold is exceeded. This modality can be used together with accelerometer-equipped sensor nodes for surveillance applications. Finally, in Query-driven mode, nodes report sensor values only in response to user queries. Moreover commands can be sent to sensor nodes by enabling control applications. Other changes, regarding network statistics and events management are not discussed here for sake of space.

The IoT-MHECHA App is shown in Fig. 5(a) and has been developed with Blynk [20], one popular IoT platform used to connect IoT devices to the Cloud. The App can



(a) (b)

Fig. 5. (a) IoT-MHECHA App; (b) example of notification.

be used to deliver multimedia contents to visitors in order to enhance their visit experience. The App allows the visitor to select a set of Artworks of Interest (AoI) before to start its tour and than, during the tour, to be informed when he is near to one of the selected AoI by simply receiving a notification directly on his mobile device, as shown in Fig.5(b). After notification, the visitor can access through its smartphone to all multimedia contents available for the selected AoI.

IV. A CASE STUDY

To underline the high level of versatility of the developed system here is reported a case study that can be considered in the middle between an indoor and an outdoor one. This case was chosen to validate the system for outdoor applications under controlled conditions comparable with laboratory ones. It is the courtyard of Municipal Palace of Messina, "Palazzo Zanca" Sicily, Italy [21][22].

Fig. 6. Courtyard of "Palazzo Zanca", Messina, Italy [22].

The city of Messina was founded as Greek colony in a period around 757 B.C. In the last quarter of the twentieth century, an excavation campaign was started inside the municipal courtyard which highlighted numerous stratifications covering a time spanning from the Roman Empire period to the threshold of the 1908 earthquake [23][24]. As it is known, the walls that are brought to light undergo a violent alteration of the balance achieved which strongly damages their conservation. In particular, the excavation has shown, over the years, numerous cycles of flowering of weeds which has led to cyclic scrapping operations. It is clear that the condition of the finds is currently exposed in all its fragility and that it needs adequate solutions to monitor the state of the walls in order to contrast the constant aggression of the atmospheric environment in the site surrounded by vehicular traffic and proximity of the sea. The possibility of checking the hygrometric conditions of the exposed walls as well as the potentially dangerous environmental factors for conservation, suggested the idea of allocating appropriate sensors on the site that allow continuous maintenance, the frequency of which can be optimized using the data collected during the continuous site monitoring.

The planimetry of the courtyard is shown in Fig. 4 together with one of the deployment schemes used for the measurement campaign. Measurement results and detailed comments about will be reported in a future work.

V. CONCLUSIONS

In this paper we proposed a new Internet of Things architecture for state of health and environmental monitoring of cultural heritage sites named IoT-MHECHA. The architecture supports a wide range of sensors and communication protocols and thus can be profitably used in several applications, considering both indoor and outdoor scenarios. Starting from open source software we developed a network management application (NM-GUI) and an App able to provide services to both visitors and operators. As future works we will extend the Fog layer with new functionalities (e.g. data aggregation and security mechanisms) and we will report detailed results of our measurement campaign.

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