Artefacts conservation using an IoT system

Cristina BALACEANU,
Beia Consult International, Bucharest, Romania

cristina.balaceanu@beia.ro

Roxana ROȘCĂNEANU,
Beia Consult International, Bucharest, Romania

roxana.roscaneanu@beia.ro

Robert-Alexandru STRECHE,
Beia Consult International, Bucharest, Romania

robert.streche@beia.ro

Filip-Emanuel OSIAC,
Beia Consult International, Bucharest, Romania

filip.osiac@beia.ro

George SUCIU,
Beia Consult International, Bucharest, Romania

george@beia.ro

Abstract

The Cultural Heritage protection and conservation is a matter of particular interest because every work of art suffers some deterioration over time. Such degeneration depends on the type of material, the action of external weather conditions and human factors. Ideally, works of art *should be preserved in stable and controlled climatic scenarios, which should be monitored and recorded accordingly. This paper aims to present a system for monitoring the factors that influence the degradation of artefacts and maintaining a pleasant environment for museum visitors. The preservation of historical objects can be maintained by detecting the levels of pollutants in museums. The main factors monitored are temperature, humidity, vibrations, air pollutants (CO, CO2, NO2, SO2) and volatile organic compounds. The proposed IoT system will be a cloud-based solution that aims to offer a wide range of functionalities, performing an individual analysis for each type of material (paintings, metals, textiles, etc.). The prototype will consist of monitoring stations, data collection and management server, cloud database, visualization, and alerting platform. The innovative feature of the technical solution is the integration of the sensors in the Cloud, which can provide real-time data in case of exceedances of nominal values. The results obtained from constant monitoring over a long period of time indicate the principal causes of the deterioration of art objects in museums. Thus, with the help of the whole system, immediate decisions can be taken for the conservation of artefacts. The study proved the scalability, reliability and efficiency of the pilot system by reducing the number of events caused by chemical and physical processes that contribute to artefact degradation.*

Keywords: *Artefacts, IoT, Cloud, real-time data*.

1. Introduction

Given the technological developments in IoT and Cloud Computing in recent years, new perspectives are emerging regarding wireless microclimate monitoring in museums for art conservation. Lately, wireless sensor networks have been developed to monitor air quality and the materials from which objects are made. These networks have proven to be effective in assessing the conservation conditions of exhibits.

Remote monitoring of factors affecting the condition of works of art can improve their long-term conservation and promote the value of cultural heritage for future generations. According to current technology, remote monitoring is mainly based on the Internet of Things (IoT) concept. An IoT approach to art conservation would involve the installation of sensor nodes and gateways for data transfer to the Cloud. The application of this IoT approach would allow online monitoring and continuous surveillance of each artwork, giving easy access from the Cloud to the data recorded from electronic sensors, improving safety and preventive conservation [1].

The Internet of Things (IoT) involves the ability of objects to communicate intelligently with their environment to provide actual services via the internet. Remote monitoring and management of the environment is enabled by IoT sensors and aims to improve the preservation of cultural heritage. The advantages of using IoT technology are high flexibility of the system, low cost of implementation, ability to monitor real-time parameters within the museum and low energy consumption.

This project aims to document the adverse effects on works of art and historic buildings to mitigate and prevent their deterioration. The architecture presented in the paper presents the key to the realization of a prototype that facilitates the monitoring of museum environmental parameters and the maintenance of an optimal level for the conservation of historical objects. The prototype communicates with a web platform to which the measured parameters are sent and can be visualized as graphs, tables, or charts to be easily interpreted and analyzed. The IoT system consists of two monitoring stations located outside and inside the museum, with low energy consumption. The outdoor station uses a solar panel for power, and the indoor station is programmed to send data at a set time interval to streamline energy consumption.

The paper is structured as follows: Section II presents the main factors influencing artefact conservation, as well as the state of the art of IoT technologies for air quality monitoring in museums, while in section III, we propose and describe a new IoT platform for preventing art object degradation. Section IV highlights the experiments conducted and their results. Finally, Section V comprises the concluding remarks and new approaches to maintain historical objects in the best possible condition.

2. Related work

Today, climate change and air pollution affect many industries and sectors globally. One of the areas affected is museums and heritage buildings, as many artefacts can be damaged or even destructed due to these environmental and climate changes.

To protect art objects [2], we need to have sufficient information about them, one of which is the material composition of the heritage. Heritage can be affected by external pollutants such as gases and particles from vehicle exhausts. These pollutants can enter museums or places where objects are kept and degrade them. Some typical outdoor pollutants are sulphur dioxide (SO2), nitrogen oxides (NO, NO2), hydrogen sulphide (H2S), carbonyl sulphide (COS) and carbon disulphide (CS2), ammonia (NH4) and peroxides such as ozone (O3). Inside, there are also threats such as cleaning products or chemicals. Organic pollutants (formaldehyde), formic acid, acetic acid, ozone, sulphides, and volatile substances threaten art objects.

The air quality inside museums is an essential factor for the conservation of exhibits, as substances in the air can cause degradation of artefacts and valuables whether or not they are in display cases. Chiantore et al. [3] present the role and impact of materials used in the construction of museum display cases, which are considered sources of hazardous substances for the integrity of cultural heritage objects. Acetic acid is a substance that causes corrosion of bronze antiquities, lead artefacts and copper alloys stored in wooden cabinets.

Air quality is also studied in the article [4], as it is a source of pollutants of art objects. The study results show that the contribution of particles (calcite, clays) and substances such as RH, O3 caused by the restoration around historical museums can degrade the objects in the museum over time. Carbon dioxide reflects the human presence in a room and is a gas that has a limited effect on the degradation of materials. Nitrogen dioxide is a primary pollutant emitted from industrial facilities, leading to the degradation of art objects through oxidation processes. Ozone is a secondary pollutant that degrades materials through oxidation mechanisms.

Azian et al. [5] highlight the air quality in museums to determine if it is acceptable for both museum employees and the visiting public. The parameters measured using a diffusion tube are the levels of NO_2, NO, SO_2 and O_3. The experimental results come from one-month monitoring of the gases listed above in four different museum locations and show that the interaction between the museum and the outdoor environment was well controlled.

In the paper [6], the authors present an Internet of Things (IoT) based system for monitoring and controlling the indoor environment of the museum. Information about the artefacts' environment is collected in real-time and sent to a gateway, then forwarded to a Cloud for storage and analysis. Following the analysis, appropriate decisions are made to set the museum environment accordingly. An ESP32 microcontroller was used in the development of the prototype, and sensors for measuring air temperature and humidity, light, visitor presence.

Regarding the solutions mentioned above and the importance of air quality in preventing the degradation of art objects, the present work consists in implementing a system for monitoring critical factors influencing the deterioration of different materials, thus leading to the preservation of artefacts. The introduced approach uses high-precision commercial sensors and designs a real-time museum monitoring system to alert maintenance personnel if the nominal value limits are exceeded.

3. IoT system for artefact conservation

The degradation rate of any material is generally determined by a limited number of environmental parameters that can be grouped into four categories corresponding to the following agents of deterioration: incorrect temperature (T), incorrect relative humidity (RH), radiation and pollution (Fig. 1).

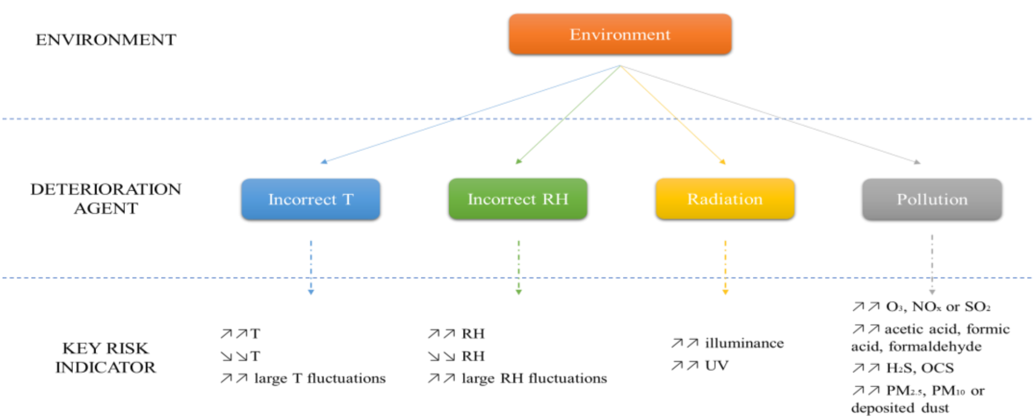

Fig. 1. Schematic overview of the different levels on which the relevance of the environment for heritage conservation is evaluated

3.1. Relevant parameters

Parameter values cannot be too low, too high or with excessive fluctuations without increasing the risk of damage. This means that the level of risk can be estimated by comparing the measurement of an indicator with the corresponding target value found in literature, guidelines, and standards.

After analyzing and assessing the risks to which art objects may be exposed, it was necessary to continuously monitor air quality and other deterioration factors. Therefore, the conservation of art objects can be maintained by detecting the levels of pollutants in museums.

3.2. Architecture of the proposed system

The proposed system will be a cloud-based solution that offers a wide range of functionalities at an affordable price. The solution can be implemented quickly to monitor art objects from the beginning of the project, benefiting from a comprehensive analysis.

A significant advantage of the prototype resulting from the project will be its modularity, making it easy to configure according to the customers' needs, thus fully justifying the cost of the communication services offered.

A functional schematic of the solution realized in the MUSEION project is shown in Fig. 2. The innovative feature of the technical solution is the integration of sensors in the Cloud, which can provide real-time information in case of overshooting of the nominal values.

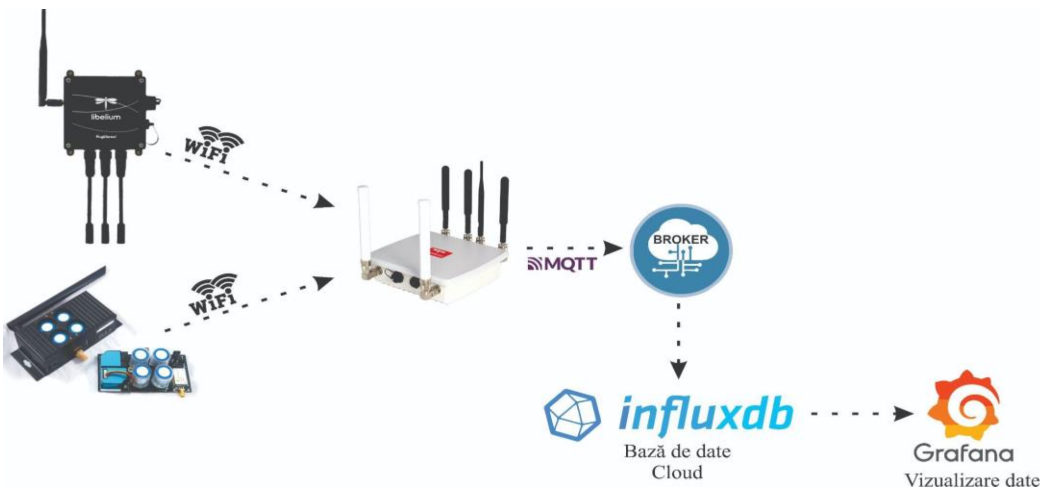

Fig. 2. System architecture
Source: Architecture realized within the MUSEION project

The system architecture consists of two monitoring stations, one located outside the memorial house, which will monitor: carbon dioxide, nitrogen dioxide, sulphur dioxide, temperature, humidity, pressure, and brightness; and a second station, located inside, to monitor: temperature, humidity, dust particles, volatile organic compounds, ozone, vibrations, ammonia, brightness, carbon dioxide and nitrogen dioxide. The data will be collected in a Gateway via Wi-Fi and then sent using MQTT to a Broker. Once the data is in the Broker, it will be stored in a database, namely InfluxDB.

The database is intended to keep the data for parameter analysis over a long time. Using Grafana, parameter analysis can be visualized in the form of graphs, tables, and charts. Additionally, thresholds can be set in this platform for each parameter. In case of unpleasant events, exceeded nominal values, museum caretakers are immediately alerted to reduce the risk of artefact damage.

4. Results

The evaluation of the IoT system architecture for artefact conservation was carried out by implementing the prototype inside a museum, where it monitored the main damaging parameters of historical objects.

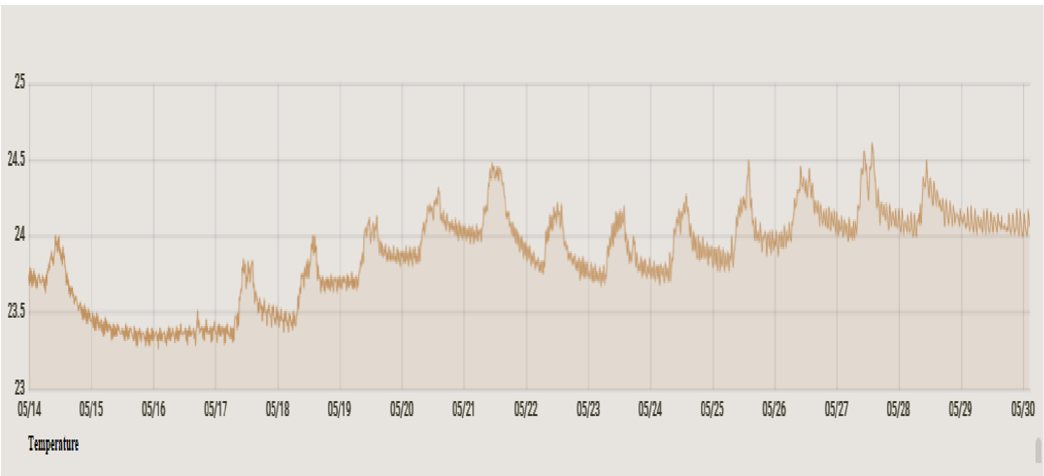

Fig. 3. Air temperature
Source: Grafana own platform

Temperature is critical in the deterioration process of art objects, as it can accelerate chemical reactions, causing artefacts to deteriorate more quickly. Keeping museum objects at a low temperature prevents the growth of living organisms. On the other hand, high temperatures deteriorate objects and accelerate the chemical process. The air temperature (Fig. 3) should be maintained between 20 and 25 Celsius degrees to provide a suitable climate for preserving historical objects.

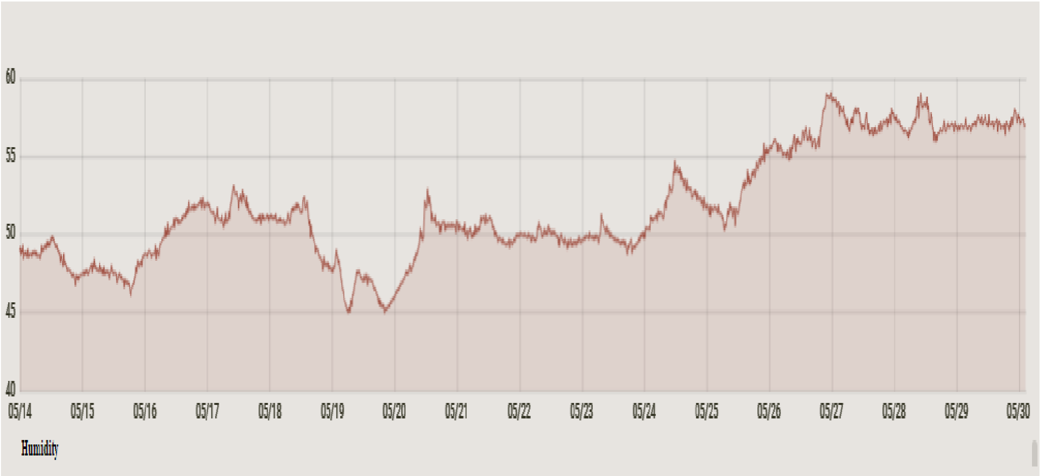

Fig. 4. Relative humidity of the air
Source: Grafana own platform

Humidity (Fig. 4) is the amount of water vapor in the air, expressed as a percentage. High relative humidity causes the expansion of organic materials, promoting biological activity and absorption of moisture and potentially toxic salts into the material's pores. In general, the relative humidity for any museum piece should be between 45 - 60%.

Fig. 5. Light intensity
Source: Grafana own platform

Light is an energy form that can have different colors and causes damage to the surface of fragile objects such as paintings, drawings, textiles, and other organic objects, thus reducing their strength. The most damaging ranges of the light spectrum are ultraviolet waves (due to very short wavelengths, which produce spectral-chemical effects on artefacts) and infrared waves (long wavelengths damage art objects through their heat action). In Fig. 5, we can see the light intensity values measured by the sensors, which are within the nominal limits for preserving historical objects.

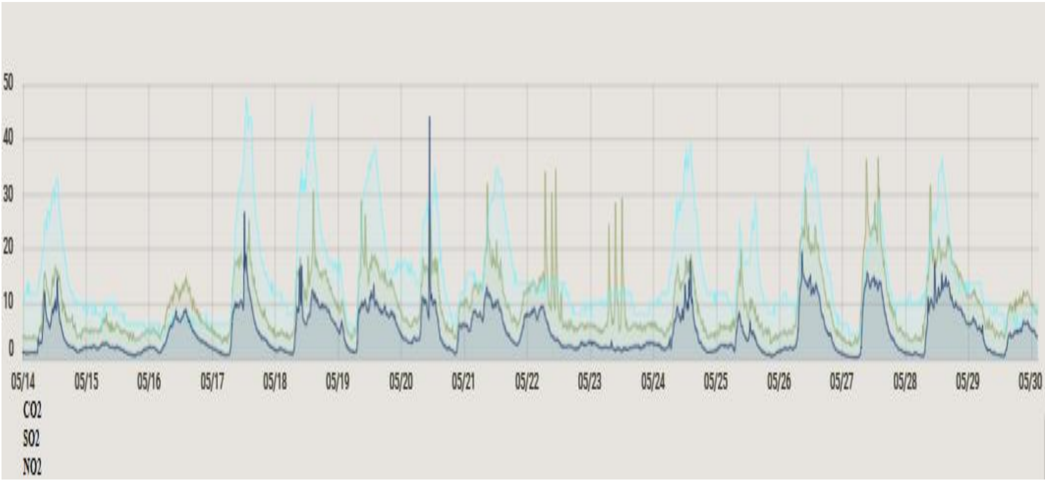

Fig. 6. Air pollutants (CO_2, SO_2, NO_2)
Source: Grafana own platform

The main pollutants hazardous to archaeological objects are carbon oxides, sulphur, and nitrogen (Fig. 6). In addition, in the absence of efficient air-conditioning systems, polluted air from the atmosphere can also enter the display cases, contributing to damage to the objects. The quality of the air inside the museum is also an important element to monitor to improve the visitor experience and provide optimal conditions for visitors to carry out their activities. The values measured by the sensors are within the permissible limits so as not to damage the exhibits in the museum.

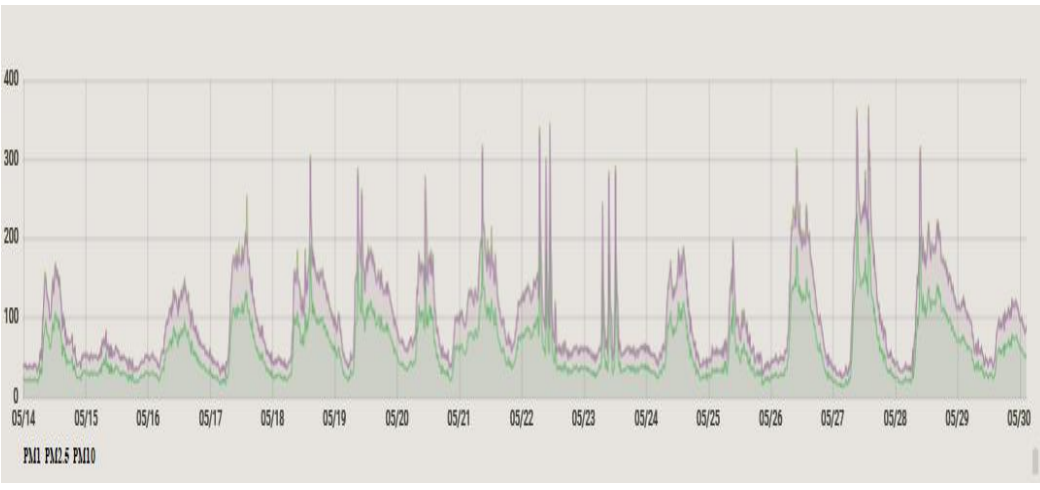

Fig. 7. Particulate Matter (PM_1, $PM_{2.5}$, PM_{10})
Source: Grafana own platform

In Fig. 7, we can see the values measured by the particle matter. Particles can come from mineral substances (limestone, silica), smoke, hair, plant and animal debris, lint, flaking skin. Dust particles can be produced by materials affected by physical-mechanical factors (road traffic, industrial processes, domestic). Because of the processes they cause (condensation, corrosion), dust particles indirectly degrade art objects, providing a favorable environment for the growth of microorganisms. Lacquered surfaces and paintings are particularly affected due to scratches that can occur during improper cleaning processes.

5. Conclusions

Since the solution proposed in this paper is in its infancy, several experiments have been carried out, and first conclusions have been drawn. The aim of the work was to evaluate the relevance and impact of certain parameters on the conservation of art objects in museums. The experimental data are acquired from two Libelium Smart Environment Pro stations located outside and inside the Ion Minulescu Museum in Bucharest. Through the proposed experiments, the values of the factors influencing the degradation of the artefacts were identified, and it was found that the storage condition of the museum collection is under control, with constant temperature and humidity and low or below detection limit of gaseous pollutants. The museum in which the monitoring stations were located contains a mixed collection of artefacts made of different materials, such as textiles, paper, metal alloys, natural organic materials, etc. These objects made of different materials are at risk of deterioration due to environmental factors such as light, temperature, humidity, and indoor and outdoor pollutants.

Based on the acquired data, we can implement algorithms to calculate indoor air quality index (IAQ) specific to cultural heritage applications as a very near future activity. IAQ consists of including a factor related to the "state of preservation" of artefacts in the calculation algorithm. There are still unresolved challenges in implementing the proposed system in multiple locations to compare the factors monitored in museums.

Acknowledgements

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