CollectionCare: an affordable service for the preventive conservation monitoring of single cultural artefacts during display, storage, handling and transport

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Abstract. In recent years there has been growing interest in the development of devices and software packages that allow museum decision-makers to manage the environmental conditions in collections and estimate the evolution of degradation of objects. A system able to monitor the environmental conditions but also to provide warnings and recommendations about failure boundaries would optimize conservation actions and strategies thus ensuring proper conservation of the collections in the long term.

CollectionCare project aims to develop an innovative and affordable decision support system for the preventive conservation of cultural objects in small and medium-sized museums by combining research and technological advances in monitoring systems (sensor nodes), wireless communications, cloud computing, big data, and material degradation models.

Validation and demonstration activities for the CollectionCare system will be carried out in six different European museums. To this end, communication efforts will be developed to promote the importance and applicability of these technologies in the conservation of cultural objects. All this in order to increase citizens’ awareness of the importance of preventive approaches for the conservation of the European cultural heritage.

1. Introduction

Preventive conservation (PC) aims at preventing and minimising the risk of irreversible damage to cultural collections due to the environmental factors (relative humidity (RH), temperature (T), light (L), air pollutants (AP) and vibration (V), etc.), to which collections are subjected. Establishing PC strategies in collections involves the implementation of environmental recommendations to provide stable environments that ensure the stability of cultural objects in the long term but also the establishment of proper control procedures to monitor such conditions [1].
However, recording environmental data is not necessarily sufficient to estimate the risk that these conditions pose to the exposed cultural objects, as the material heterogeneity and complexity that they usually present make this evaluation very complex. This means that environmental monitoring alone cannot be considered an effective preventive conservation strategy. An effective system should link environmental monitoring to predictions of the kinetics of alteration of cultural materials in relation to the above-mentioned environmental parameters.

Nowadays, different technological solutions are available to monitor and record the environmental parameters that surround cultural objects in the museum context [2]. However, they lack a predictive function that estimates the degradation rate caused by the exposure to this environment and which provides conservation recommendations for their proper preservation. The CollectionCare project is intended to design a preventive conservation system that links research on degradation models with new technologies in sensors, cloud computing and big data, in order to provide an environmental monitoring system that helps predict how materials will behave over time in a given environment and provides conservation warnings according to European preventive conservation standards.

The following sections will describe in detail CollectionCare’s decision support system, the project structure, the different demonstration sites and the collections selected as case studies. Finally, the work done so far and future perspectives for the coming years are presented.

2. CollectionCare project decision support system

CollectionCare project aims to develop an innovative PC decision support system targeting the needs of small to medium-sized museums, which often cannot count on a sophisticated environmental monitoring system or on qualified personnel to maintain it. The system will integrate current research and technological advances in sensor nodes, wireless communications, cloud computing, big data and material degradation models into a single affordable system, in order to suggest appropriate conservation guidelines for museum collections. To accomplish this, the CollectionCare system intends to continuously monitor the environmental conditions for selected cultural objects in different scenarios (display, storage, handling or transport), through an internet of things (IoT) sensor node device placed near them.

On the one hand, the system monitors environmental conditions at room level, but the information collected, stored and analysed is for each individual object. This will allow cost optimisation, as with a single device it is possible to monitor each individual cultural object within the same space, when they do not require individualised monitoring. On the other hand, it is also possible to monitor the microclimate conditions of the immediate environment surrounding the object, allowing a more precise monitoring when the sensitivity and vulnerability of objects require it.

Later on, all the information obtained by the sensor nodes is transferred, stored and analysed in the cloud (cloud computing platform for big data) and integrated with advanced material degradation models. These degradation models are able to provide users with information on the evolution of the degradation of the artefact, as well as warnings and recommendations to ensure the proper long-term conservation of each object.

The CollectionCare system is considered to be affordable, as it offers not only a device, but a whole service for the preventive conservation of small and medium-sized collections. Currently, the most advanced solutions to monitor environmental parameters for cultural objects in museums are wireless data loggers that basically monitor T and RH. However, they have several disadvantages, such as their high price (ranging from €250 to €700), their low autonomy (<18 months) and their lack of degradation models to provide predictions about the material degradation of the cultural objects under such environmental conditions. This latter aspect implies that, in order to achieve a proper preventive conservation of collections, a conservator is needed to analyse the data collected by these devices. As for CollectionCare, it provides a service with an estimated current annual fee of €100 per sensor node/year which includes: a) the required hardware equipment (sensor node with wireless connectivity); b) service of preventive conservation recommendations and degradation predictions for each individual cultural artefact; c) visualisation of PC status, historic and real-time environmental conditions and PC.
recommendations, and d) a warning system, to alert end users when the environmental parameters are out of established ranges for an optimum PC. With this, CollectionCare stands out not only as an integral, innovative and high-quality service, but as a decision support system providing preventive conservation recommendation and warnings for individual objects at any time and place.

Figure 1 shows how the different aspects of the research and technology mentioned above are integrated to enable the development of the CollectionCare system. Each of the different areas that are integrated into the system is explained in detail in the three sections below: i) sensors and connectivity; ii) cloud computing and big data; and iii) degradation models.

2.1. Sensors and connectivity
RH, T, L, AP and V are the most common degradation agents in cultural heritage. They are all considered in the wireless monitoring capacities of CollectionCare sensing nodes. To perform the CollectionCare monitoring plan, sensor nodes will be strategically placed, using deployment protocols and conservation guidelines to estimate how many sensor nodes need to be installed in each room and how they should be placed. The installation will be reversible, so that they can be removed when necessary, while the connectivity will be plug and play.

When monitoring a single object, the sensor node will accompany it at all times: during exhibition, storage, handling or transport. If monitoring a room with multiple objects, or when the objects are very small (e.g. coins, jewels), the sensor node will be assigned to the full set of objects. The data gathered will be processed for the state of conservation of each object individually, considering its specific nature in terms of the composing materials. By doing this, when the collection changes location (from storage to display, on loans, etc.), the objects will be assigned to other sensor nodes without any historical data being lost. In both cases, every single object monitored with CollectionCare system will have its whole life record, which will detail the history of its evolution and help to take informed decisions for its conservation.

The sensor node will consist of a miniature electronic board with sensors for the different physical magnitudes (T, RH, L, AP, V), a microcontroller to manage these sensors and a wireless radio module. Additionally, this node is a wireless multi-protocol that allows users to deal with different scenarios (e.g. exhibition, storage and transportation). For the sensor node to be efficient and have a long lifespan, power
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consumption will be a crucial aspect to consider in its design. Thus, the CollectionCare solution will be based on the use of minimal energy and appropriate sleep cycles, high-density low self-discharge batteries (e.g. Lithium-thionyl technologies) and energy harvesting techniques [3].

Wireless transmission of data from the sensor node to the cloud will be based on LPWAN (low-power wide-area network) technologies being successfully used in smart-city solutions. Custom-made firmware is integrated in the wireless radio module, combining the most successful LPWAN technologies: Sigfox and LoRa/LoRaWAN. These wireless technologies allow link budgets of around -150 dBm (minimal radiofrequency energy level to receive a signal), behaving properly on thick walls and long distances (700m), which are the usual limitations found for this kind of wireless systems in many museums and historical buildings.

LoRaWAN technology uses a gateway-based solution (a kind of data hub that retransmits data to the cloud using Internet); this gateway will upload data collected by the sensors to the cloud, being especially useful when many sensor nodes are used or during the transport of objects. At the same time, if connectivity problems might arise during transport, the edge computing technology will be use allowing the gateway to continue collecting data from the sensors and analysing them without any interruption. However, the sensors will have the ability to perform this task (upload data collected to the cloud) on their own using Sigfox technology, although to reach the cloud a relative high amount of energy will be needed.

2.2. Cloud computing and big data

A preventive conservation cloud computing platform is being developed in CollectionCare through an agnostic provision to the cloud (for example, being able to deploy an Infrastructure as a Service -IaaS- in Amazon Web Services) based on standard open source software that guarantees interoperability, independence and future evolution. The computer provision is based on automating the provision of computing resources according to the number of cultural objects to monitor and the complexity of the material numerical models (e.g. using ATOS’ ElasticBDAnalytics Asset to allow automatic provision of computers). This will provide automated deployment and operation of Big Data and Machine Learning clusters over diverse cloud technologies and providers.

Data provided by the sensor nodes will be uploaded to the cloud using edge computing technology, achieving a data collection infrastructure that is easy to maintain and evolve. The edge computing approach has been added because it enables local processing capability that could be crucial for unexpected harmful situations, such as water leakage, that can be handled locally and practically in real time without requiring connectivity to the cloud.

Considering the high volume of data (10 Mbyte per year for each artefact) to be dealt with, CollectionCare data storage will make use of data technology stores based on HDFS and NoSQL databases such as HBase or MongoDB unstructured data. NoSQL databases do not impose a predefined table structure, allowing them to adapt to new data types without requiring a database redefinition.

Data obtained by the sensors will be analysed using complex numerical models (degradation models) that will require high amounts of computational power. Atos Data Analytics and Atos Codex deployment tools will allow CollectionCare to go the extra mile in deploying big data frameworks and compatible machine learning libraries, in order to deal with big amounts of data to guess behaviours and patterns.

2.3. Automatic analysis through degradation models

To predict the extent of damage that climate conditions can cause to cultural objects, the CollectionCare system will be based on the application of degradation models for the analysis of environmental data. In particular, the project aims to define a structured approach to predict the extent of degradation of a specific type of cultural object by means of degradation models. The starting point will be to consider models from the existing literature and to extend and tailor them to describe the specific nature of the objects (material) and the degradation agent considered (humidity and temperature fluctuations, light, air pollutants and vibrations) [4,5,6,7]. As the degradation process strongly depends on the material properties of the artworks and the environmental conditions to which they are subjected [8], four types
of objects are considered within the project: canvas paintings, wooden objects, paper objects, and metal objects. These types of objects are frequently found in collections and are thus representative of typical degradation scenarios. The environmental history information provided by the museums will be used as input parameters for the numerical algorithms of the specific material degradation model. These models will be integrated to allow the characterisation of the degradation of different materials of the same object due to different degradation agents and their interaction.

The prognosis of the conservation condition of the monitored objects provided by the CollectionCare system and the recommendations for their PC will be the result of an automated analytical process of the collected data based on numerical algorithms made in the cloud. These algorithms will be based on different models, describing the materials ageing and degradation kinetics.

Before the analysis of the environmental data, the monitored object should be described in the preset common language with the specification of its materials (this will ensure a link between the sensor node, the cultural objects and their material characteristics in the software). The data collected from the selected objects will be cross-correlated automatically in the cloud with the data from the degradation models or degradation parameters of each material transcribed into the computer algorithms. Also, it will be correlated with the parameters of the current European and other standards, such as EN 15757:2010 [9] and ASHRAE 2015 guidelines [10], in order to obtain degradation predictions as well as PC recommendations for their proper conservation.

3. Work Breakdown Structure of the CollectionCare project

The work breakdown and the structure of CollectionCare are represented in Figure 2. The work is organised into ten Work Packages (WP), combining system development (WP1 to WP6), project management (WP9) and related activities (WP7, WP8 and WP10).

WP1 (Definition of Collection Care System requirements) is intended to provide a thorough analysis of the specific technical requirements and baselines for development of the different elements of the start-up system (sensors, wireless, cloud computing for big data, degradation models and conservation standards) and to establish a common language to be used throughout the project. WP1 is defining the starting point for WP2 (degradation models), WP3 (cloud computing) and WP4 (sensor node design) by defining the relevant state-of-the-art levels for each of the professional fields involved in the project.

WP2, WP3 and WP4 will be developed in parallel. WP2 is designed to tailor and extend the degradation models that are already available in the literature and which focus on the prediction of
degradation for the different types of cultural objects, such as canvas paintings, wooden objects, paper objects and metal objects. Subsequently, all these models will be integrated and their outcomes analysed in light of the current European standards on conservation. This will allow us to provide specific degradation predictions for particular cultural objects based on their multi-material nature. WP3 will contribute to the Big Data Cloud Computing environment conservation management, which is targeted to design, based on existing technologies, an ideal cloud computing for big data infrastructure to store high amounts of information on the monitored environmental conditions and process it for later analysis. The aim of WP4 is to create an appropriate wireless sensor system (sensor nodes) to collect continuous information on physical magnitudes affecting the conservation of the cultural objects (T, RH, L, AP, V) that will be uploaded to the cloud infrastructure. This WP will focus on the design of the sensor nodes and on improving wireless communications by taking into account all the obstacles that may arise in the different spaces where the objects are exhibited, stored and transported.

Once all the previous work has been done, the different system validation (WP5) and demonstration tasks (WP6) will begin. These validation and demonstration tasks will take place in seven partner museums, where a set of forty objects from each institution have been selected to be monitored and tested by the CollectionCare system during the last 6 months of the project (WP6). All the technologies and models developed previously will be integrated to identify and observe that the CollectionCare PC support system works effectively in a real scenario with different cultural objects in exhibition and storage spaces, as well as during loans and transport.

Management (WP9) and ethics (WP10) tasks are carried out alongside all project stages to ensure the successful achievement of the project objectives, outputs and impacts. Finally, WP7 and WP8 will ensure a proper communication and dissemination of the project as well as the exploitation plan to increase the potential impact and acceptance of CollectionCare system in its corresponding market.

4. CollectionCare in context: demonstration sites and case study collections
As mentioned above, real scenarios have been selected to perform validation and demonstration tasks in order to assess how the CollectionCare system works. Within the consortium, the project counts on six institutions that will act as demonstration sites:

- Diputación Foral de Álava. Arms Museum and Fine Arts Museum (DFA), from Alava, Spain
- The Ethnographic Open Air Museum of Latvia (OAML), from Latvia
- Valencia Institute of Culture (IVC), from Valencia, Spain
- The Royal Museum of Art and History (KMKG), from Brussels, Belgium
- Historical and Ethnological Society of Greece (IEEE), from Athens, Greece
- Rosenborg. The Danish Royal Collection (RDC), from Copenhagen, Denmark

Guidelines have been set to help these institutions select the objects to be used as case studies. The guidelines were initially established on the basis of a "best fit" to the technical requirements set out from the beginning (WP1).

Objects with a documented conservation history, with a known material composition and techniques and with records of past environmental history were chosen. The objective was also to select objects that showed a variety of conditions and levels of reactivity when subjected to environmental variations, and that were located in different spaces (exhibition and storage rooms, as well as transportation scenarios for museums loans). Finally, the criteria established were:

- 40 objects to be selected, ideally 10 from each material category (canvas painting, wood, paper, metal), although several collections were not able to satisfy these conditions as they had very few – or no – objects of certain materials in their collections.
- Objects that have a known -preferably documented- conservation history.
- Objects that have been part of the collection for a long time.
- If possible, objects that have past historical environmental data.
- Both treated and untreated objects should be included.
- Some objects should have been constantly on loan and some others not.
Various sizes should be included

In order to evaluate different scenarios and spaces where the objects are exhibited or stored within these institutions, wireless connectivity factors and the construction features of the buildings and spaces in which these objects are located, were also taken into account when choosing the objects.

In August 2019, the different objects from each institution were selected and a conservation report was compiled for each cultural object. A total of 215 objects were singled out, including 50 wooden objects (23%), 62 works on paper (29%), 44 canvas paintings (21%) and 59 metal objects (27%). The four examples shown in figures 3 to 6 are representative of the different objects selected for the development of the project.

**Figure 3.** Landscape canvas painting attributed to Darío de Regoyos (1857-1913). Painting belonging to the collection of the Fine Arts Museum of Diputación Foral de Álava in Spain.

**Figure 4.** Deck of 52 cards of cellulose paper from the 18th century, supposedly belonged to Queen Anna Sophie Reventlow. Object belonging to the Royal Danish Collection, Rosenborg in Copenhagen, Denmark.

**Figure 5.** Dowry painted wooden chest. 19th century furniture dated 1807. Object belonging to the Ethnographic Open Air Museum of Latvia.

**Figure 6.** Italian metallic sword of the 15th century. Object belonging to the collection of Alava Arm museum of Diputación Foral de Álava in Spain.

5. **Conclusion. Progress, future perspectives and expected outcomes**

In the first year of the project, CollectionCare has made significant progress defining the requirements to start the development and tailoring of the degradation models (WP2), the big data and cloud computing infrastructure (WP3) and the design of the wireless sensing nodes (WP4). For the degradation models, an initial sweep has been made identifying and obtaining all the necessary information and details on the current degradation models of canvas paintings, paper objects, wood objects and metal objects. For big data and cloud computing, preliminary investigations have been carried out to evaluate the uploading of historical data to different types of databases. Amazon DynamoDB has been the database proposed for use as storage for sensor measurements. Also, initial research has been carried out to define the necessary requirements for the design of the sensor node housing and the development of the first prototype of the "basic" sensor node. A first electronic diagram of the sensor and the design of the printed circuit board (PCB) have been drawn up, so an initial batch production of "basic" sensor
nodes has been started. Finally, small tests of the sensor node have been done to validate its communication function and the environmental measurements it performs in museum settings such as the Museum of Informatics of the Universitat Politècnica de València in Spain and the Museo delle Origini of the Sapienza Università di Roma in Italy.

Over the next two years of the project, development of the three main areas of the CollectionCare system such as connectivity and sensors, big data cloud computing and degradation models will continue. The aim is to be able to integrate these components into a single system by early 2021 and to start the validation procedures. These tasks are designed to identify any corrections or improvements to be made before the demonstration phase begins. Finally, 6 months before the end of the project, the demonstration activities will initiate in the different institutions to evaluate the usability, effectiveness, efficiency and end-user satisfaction of the functionalities provided by the CollectionCare system.

Finally, a meeting called “Sensors and Computer Modelling in the Conservation of Cultural Heritage” will take place in Valencia at the beginning of 2022 to disseminate the project research results and assess the possibilities of CollectionCare in relation to the museums and collections, with particular focus on PC services for the conservation of cultural heritage. Also, within this activity, it is intended to create a forum where researchers, museums professionals and companies can exchange ideas and explore potential areas for future research.

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