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Semantic Representation and Internet of Things in Cultural Heritage Preventive Conservation

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Abstract

Preservation of Cultural Heritage (CH) collections in the best possible condition for the longest time possible is a crucial part of CH Institutions activity, since it ensures artefacts' effective function in perpetuity. In this context, preservation processes that do not include any physical interaction with an object or collection can be regarded as preventive conservation. Preventive conservation measures and activities include among others the monitoring and management of environmental factors, in order to reduce potential risks of collections condition. The advent of the Internet of Things (IoT) can help towards this goal by automating the collection of data through sensors deployed in the cultural space and providing available services based on the IoT ecosystem. IoT technologies can facilitate the preventive conservation of tangible CH by exploiting streaming data produced by networks of sensors that keep track of changes in environmental parameters of a particular museum, in order to monitor the condition of its collections. Moreover, Semantic Web (SW) technologies could increase the efficiency of sensed data management by introducing reasoning mechanisms that will result in useful inferences regarding the combination of long-term or short-term records of sensed data and material decay. This work summarizes current state-of-the-art frameworks and monitoring systems that collect data from sensors in CH environments and the use of semantic web technologies for the efficient management of conservation and sensor data. Based on this study, it proposes an IoT infrastructure with semantic tools, which aims to enhance preventive conservation science.

Keywords:

Semantic Web Technologies, Internet of Things, Preventive Conservation, Museum Collections.

1. Introduction

Preservation of Cultural Heritage (CH) collections in the best possible condition over time is crucial for Cultural Heritage Institutions (CHI) activity. Its importance can be better perceived considering that the conservation and protection of cultural objects ensure their effective function as part of a CHI collection in perpetuity (Caple, 2012). Inevitably, each artefact undergoes certain deterioration with time, which depends on its original materials and structure, the environmental factors of its current or past environment, as well as any human activity that may have affected it. Therefore, it is necessary for the scientists and professionals of CHI to understand the mechanisms and take measures to avoid or minimize the extent of the future degradation processes that could alter objects' material and properties.

Preservation processes that occur without physical interaction with an object or collection can be regarded as preventive conservation (Caple, 2012). Preventive conservation indirect measures and activities include -among others- the monitoring and management of environmental factors, aiming to reduce potential risks of collections condition. In the context of preventive conservation, sensors are used for the collection of data related to ambient conditions of spaces where the objects are exhibited or stored (Alsuhly & Khattab, 2018). Since ambient factors act cumulatively, the immediate detection of harmful environmental changes is important. Therefore, the advent of the Internet of Things (IoT) can help towards this goal by allowing remote monitoring and by automating the data collection through sensors deployed in the cultural space (Perles et al, 2018). The installation of sensor nodes and the easy transfer and access of data through a platform would provide continuous supervision of individual objects or groups.

Furthermore, the IoT ecosystem can be the base for the development of intelligent services facilitating management and action planning for CH conservation specialists. Particularly, the application of semantic web technology to the IoT infrastructure could benefit the representation and integration of different data and provide reasoning upon them (Bajaj et al, 2017; Moraru & Mladenić, 2012). A conceptual representation of domain knowledge including conservation and sensor data could support their interoperability, as well as their correlation. The combination of existing knowledge about an object in relation to short or long term records of sensory data may lead to a more efficient protection from a harmful condition (Barnaghi et al, 2012).

An IoT approach for the monitoring of collections could be undoubtedly beneficial for preventive conservation sector, while the application of semantic web technologies presents further potential for data management and knowledge extraction. In the remainder of this paper we first present the state of the art in the two axes of our study: frameworks and monitoring systems that collect data from sensors in CHI environments and the area of semantic web technologies for conservation data and sensory data management. Afterwards, we propose an IoT infrastructure with semantic tools, which aims to enhance preventive conservation science approaches in museum collections.

2. Motivation and Related Work

2.1. Sensors and the Internet of Things in Preventive Conservation

Monitoring and controlling the environmental conditions of cultural sites, historical buildings and museum collections in order to prolong their lifetime, is an important task in CH domain (Alsuhly & Khattab, 2018). Regarding particularly the internal microclimatic control of CHI spaces, this task may also be considerably complex. The ideal atmosphere may differ for each item or group of items in a collection, according to their original materials, history and current condition state (Perles et al, 2018). Therefore, different rooms or individual showcases may have different requirements regarding environmental conditions. In this context, there are some interesting projects and articles about the recording of physical parameters and the application of microclimate monitoring and control systems including sensors or more complete IoT architectures for indoor spaces, both of CH historical buildings and CHI exhibition and storage rooms. It is important to mention that although we are focused on CHI indoor spaces, we have included both kinds of cases in our study in order to have a more complete picture of the technologies used for indoor environmental monitoring and control in CH.

First and foremost, sensors are small sensing devices which change their status according to physical stimulus and can be attached to larger objects or specific location (Peralta et al, 2010; Perles et al, 2018). In most typical scenarios of CH monitoring, sensors measure and determine temperature and relative humidity in order to ensure that they are maintained under constant levels or in some cases precise values. When necessary, sensors can be also used for the detection of light and other forms of radiation, pollutants (such as carbon dioxide, several types of acids, dust particulates, etc.), pests and vibration (Peralta et al, 2010). The data acquisition interval may also differ according to the different devices and most importantly the different use case scenarios. Therefore, a sampling rate may vary from one record measure per 10 minutes, per hour or even per day (Perles et al, 2018). Eventually, the provided data can be downloaded to a computer and analyzed on demand or be transmitted in real-time to more complex devices without power constraints, for further aggregation and processing (Ayala et al, 2014; Visko et al, 2017).

An approach for artwork monitoring included the use of commercial dataloggers, which are autonomous devices powered by batteries with the advantage of being easy to install, wire-free, and small (Visko et al, 2017). The authors monitored the microclimate of a historical building during a period without visitors and compared it to a similar monitoring process after the building was open to visitors, using cheap but reliable devices that measured temperature, humidity and illuminance. Although useful for short monitoring procedures, the dataloggers are less appropriate for continuous monitoring, especially in cases of remote locations because of the requirement for regular manual download from each device.

A similar approach was conducted for the monitoring of the frescoes of the cathedral of Valencia (Garcia, 2010). During the restoration process, wired probes were installed, which measured the relative humidity and temperature of several spots on the frescoes. The sensed data were stored into a microcontroller and were weekly downloaded to a laptop for further processing, which reduced the download effort but did not eliminate it. In addition, a combination of wireless nodes and dataloggers was used for the microclimatic monitoring of

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the Duomo (Aste, 2019). The daily monitoring process included four (4) hourly cycles of data monitoring (using computers installed and connected to the sensing devices). Finally, a recent review of available sensor devices and dataloggers (with or without IoT connectivity) can be found in (Valentini, 2018).

Focusing particularly on environmental monitoring of CHI internal spaces, in the work of presented by Ayala et al. (2014), an agent-oriented system called iMuseumA was implemented at the Museum at the Informatics School of the University of Malaga. Software agents were embedded in a set of sensors and lightweight devices, providing environmental and contextual information. Regarding particularly the environmental data collection, Libelium was used for the development of SensorAgents, providing special modules called sensor boards. The events sensor board, which was used, included sensors for measuring luminosity, temperature and presence by means of PIR sensors. The agents principal activity was the gathering and processing of information from the sensors in a certain frequency. New data were internally stored, while in case of changes detection they sent a message using the available communication technology to the corresponding agents. Additionally, the museum staff was able to get this information from the SensorAgents using the mobile application of the system, which allowed the request and visualization of contextual information for specific spaces.

In the context of WISE-MUSE project (Peralta et al, 2010) the deployment of a Wireless Sensors Network (WSN) and a monitoring system for a contemporary art museum was proposed. WISE-MUSE project used sensor nodes for collection of data related to humidity, temperature and light, which was sent wirelessly to a database through a sink node connected to a computer. The team of the project developed a new wireless sensor node, which corresponds to ZigBee end devices. It was designed for environmental monitoring, while it met the requirements of the museum in terms of the size (small dimensions), the cost and energy consumption. An interesting part of this work is also the development of the monitoring system, including an awareness and a web-based visualization tool. The awareness tool provided a view of the network, integrating data in a 3D representation of the network and the museum, while a web-based tool visualized data in different formats (tables, graphs, colour gradients etc). In this way, museum professionals were able to consult collected data in real time or historic data whenever needed in an efficient way. Furthermore, automatic control of a dehumidifying system was deployed, in order to regulate relative humidity levels inside the rooms where the WSN was applied. The system received environmental data from the WSN through the data analyzer and the localization algorithm module. A similar, more recent approach is described in (Klein, 2017) where more than 200 sensors were installed forming a WSN that environmentally monitored a confined space of the Metropolitan Museum of New York.

Given the utility and function of sensors and sensor networks for the ambient condition monitoring and recording, the idea of intelligent communication and coordination among cultural objects, their surrounding environment and people, seems attractive for the CHI preventive conservation domain. The IoT exploits the use of sensors and actuators allowing the remote monitoring and management of the things and their environment. It also supports connectivity with external devices, resources and platforms extending the offered applications and services and expanding the preservation system beyond the scope of a single CHI.

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Furthermore the forthcoming standardization of IoT protocols and the recent flow of out of the box IoT nodes provide cheap, efficient and easily deployed infrastructure options for automatic monitoring systems.

An IoT approach for the monitoring and controlling of different types of CH environments is described in (Perles et al, 2018). It involves the installation of microelectronic wireless systems (sensor nodes) of great autonomy able to record sensor data and transfer them (gateways) to a public or on-premise cloud. Thus, the measurements can be processed or downloaded on-line, allowing continuous supervision as well as easy access in real time to recorded data. The work is focused on the appropriate design of the nodes regarding power consumption and communication distances. The deployed nodes included humidity and temperature sensors and used LoRa and Sigfox technologies. Furthermore, the collected data was proposed to be transferred to a cloud (MongoDB), where they can be appropriately processed. Data could then be analysed and used for developing and executing predictive models in the cloud, providing recommendations and active specific protocols avoiding future damage.

Additionally, an IoT based system for museum ambience monitoring and control and collection security is presented in (Alsuhly & Khattab, 2018). It includes two types of microcontroller-based nodes: sensor nodes and actuator nodes. In the proposed system, the information about the artefacts environment and their safety conditions are collected in real time and sent wirelessly to a gateway. The collected data is preprocessed and aggregated locally in the gateway before being relayed to a cloud. Based on the preprocessing and developed decisions, information is sent automatically back to the actuators in order to implement particular actions. The museum staff can also control the actuators manually through a web-based interface. Furthermore, there is an extra data processing level in the context of a cloud-based backend. In this case, data is stored and processed in order to develop feedback decisions, while tools, which make the data accessible to users through the Internet, are provided. The communication among sensor and actuator nodes, as well as the cloud is achieved using Wi-Fi wireless communication protocol.

In the work of Asinelli et al (2018), the authors evaluate the use of a prototype device that measures environmental variables and send the collected data to an IoT platform that allows real-time visualization, analysis, and download. The device is equipped with WiFi connectivity and is assembled from lost cost parts while the authors report low power consumption that will allow for sparser maintenance intervals. Furthermore, the use of open software (ThingSpeak an open IoT platform) and hardware (Arduino) allows the exploitation of sources and application from a very active community. The evaluation was performed in an exhibition cabinet hosting 18th century ceramics, although issues of obstruction and aesthetics were not addressed.

2.2.   Semantic Web Technologies for Data Management

IoT consists of interconnecting devices and aims to collect and process data from them, but most importantly to enable applications, machines and people to efficiently understand their surrounding environments and be aware of any existing situation. This understanding and context awareness may eventually lead to intelligent decisions and meliorate the

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responsiveness or actuation for both machines and humans. However, the heterogeneity of collected data, as well as their volume and velocity makes their processing, integration and interpretation a challenging problem (Barnaghi et al, 2012; Wang, Zhang & Li, 2015).

Semantic web technologies could provide promising solutions in the IoT domain, since they promote interoperability among IoT resources, information models and consumers and facilitate data representation and integration (Barnaghi et al, 2012). Automatic annotation or enrichment of sensory data could provide machine-readable and machine-interpretable metadata for IoT resources and data, making them at the same time machine-understandable. Therefore, data will be able to be combined, managed, querying, and accessing in a more efficient and unambiguously way (Moraru & Mladenić, 2012). In this direction, Semantic Sensor Web (SSW) uses declarative descriptions of sensors/actuators, networks and domain concepts to search, query, and manage the network and sensor data (Wang, Zhang & Li, 2015). One of the most important components to this aim is the sensor ontology.

The use of ontology could ensure a common agreement on ontological definitions among different stakeholders of IoT domain. To this aim, in the past years, general sensor ontologies have been developed as well as ontologies and semantic description frameworks for more specific projects and applications (Barnaghi et al, 2009). An example is OntoSensor, an ontology that primarily adapts parts of SensorML descriptions and uses extensions to the IEEE Suggested Upper Merged Ontology (SUMO) to describe sensor information and capabilities. The ontology was developed to support sensor information system applications in dynamic sensor selection, reasoning and querying various types of sensor and it is represented in OWL format. Although OntoSensor illustrates a semantic approach to sensor description, it does not cover the representation requirements for sensor observation and measurement data (Bajaj et al, 2017).

Moreover, the Commonwealth Scientific and Industrial Research Organisation (CSIRO) ontology (Fernandez et al, 2013) is a generic sensor ontology developed to describe sensors and deployments, while it can also be used in data integration, search, classification, and workflows. Like OntoSensor, this ontology covers a wider range of concepts than the other ontologies and it describes most of the spectrum of sensor-related concepts. However, the key difference is that CSIRO ontology can describe sophisticated forms of structural and sequencing composition. In the same manner, the CESN ontology (developed by the Coastal Environmental Sensor Networks) (Calder, Morris & Peri, 2010) describes the relationships between sensors, middleware and databases. For this purpose, the core concepts of the CESN ontology are the physical sensor devices themselves, e.g. sensors as devices and their measurements.

Development and sharing of ontologies is an important step in achieving semantic interoperability on a large scale. However, it is crucial to use common existing ontologies and provide links between ontologies or to an upper-level ontology. Therefore, the W3C Semantic Sensor Network (SSN) Incubator Group proposed a more generic, field-independent model, the SSN ontology. It is a high-level schema to describe sensor devices, their operation and management, observation and measurement data, and process related attributes of sensors. SSN ontology aims to solve the heterogeneity problems associated with sensor discovery and sensor data collection but has limited concepts to support the spatial and temporal association of sensor data with the resources (Wang, Zhang & Li, 2015; Bajaj et al, 2017). It has received

consensus of the community and has been adopted in several projects. To model, the observation and measurement data produced by the sensors, the SSN ontology can be used along with other ontologies (Bajaj et al, 2017).

Furthermore, semantic sensor data can also be interconnected with domain concepts related to a specific scenario where the sensor networks are used (Moraru & Mladenić, 2012). In this context, it would be interesting the combination of an IoT ontology with domain ontologies of CH or more particularly conservation science in order to meet the needs of knowledge representation for preventive conservation data, as they have been already discussed in the introduction and Section 2.1 of the paper.

CIDOC Conceptual Reference Model (CIDOC CRM) is being considered as a core ontology of the CH domain, aiming in assisting the domain experts to organize, integrate and manage the vast amount and diversity of CH information (Doerr, Hunter & Lagoze, 2006). It provides semantic definitions for optimal integration, mediation and interchange of diverse cultural information through the Web, which may be located in different, local or even isolated information sources. Eventually, CIDOC CRM may serve as a global schema, query mediation, guideline for conceptual modeling or building information systems, or be utilized for tagging schemes development, being valuable in organizing and reusing cultural information (Bruseker, Carboni & Guillem, 2017).

CIDOC CRM has been widely used for mapping and merging of metadata standards and ontologies related to the CH domain. Additionally, it has served as the base for developing extensions in order to meet the needs of specialized fields and tasks (Moraitou et al, 2019). Particularly, up to now a number of compatible models have been developed and proposed by CIDOC CRM Special Interest Group, extending the model's main entities. Among them CRMsci model serves as a global schema for data integration related to scientific observation, measurements and processed data and is related to a significant part of preventive conservation activities in terms of the environmental condition monitoring (Doerr et al, 2015). Encoded in RDFS, CRMsci allows distinguishing the observation process from its results, as well as the observed object from a sample one. Complementary, another compatible model, CRMinf, focuses on the different arguments and states of belief based on observations and results, and therefore can be perceived as an extension of CRMsci (Stead & Doerr, 2015).

Nevertheless, there are some domain specific ontologies about conservation science representing more specifically the domain knowledge. OPPRA ontology (Ontology of Paintings and Preservation of Art), extends CIDOC CRM and merges entities of chemistry ontologies such as OreChem and OIA-ORE (Hunter & Odat, 2011). The main aim of OPPRA is the documentation of descriptions of physical artifacts, events, damage mechanisms and related digital information within the sub-domain of paintings conservation, in a reusable and machine-processable form. Additionally, PARCOURS ontology (Niang et al, 2017) models information about cultural objects, phenomena and features of events, data related to scientific study and related instruments, and information about applied treatments. It extends CIDOC CRM and CRMsci, defining new, more specialized entities and relations between them. Also, it integrates a set of thesauri aiming to manage mismatches at both the syntactic and semantic level, potentially arising within the conservation-restoration terminology. Similarly, Conservation Reasoning (CORE) ontology extends CIDOC CRM with concepts and relations

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about original materials and production techniques, condition state and conservation processes applied on artworks, particularly byzantine icons (Moraitou & Kavakli, 2018).

The knowledge representation that can be achieved with the exploitation of semantic web technologies, may facilitate reasoning upon data and therefore information inference based on existing assertions and rules. As mentioned by Barnaghi et al (2012), semantic reasoning is considered an important instrument in the domain of IoT providing resource discovery, data abstraction, and knowledge extraction. In the context of an IoT infrastructure, reasoners, which provide actual inference algorithms, can be used, while SPARQL query language can be used in order to explore the semantic descriptions. Therefore, inferences can be exploited for the information management of a whole system and the support of users' decisions and actions through recommendations. Based on the information that derives from the processed data, notification and alert services for the users can be developed taking into account the severity of a change or the potential risk. A similar idea is presented in (Ayala et al, 2014). Finally, suggestions or even potential decisions can be presented to the end users over an observation of the IoT system, facilitating their work and increasing the effectiveness of their actions.

3. IoT and Semantic Web in the Service of Preventive Conservation

3.1. Semantic Web Technologies for Data Management

Considering the previous works on the field of the IoT implementation on CH, we presume that semantic web technologies could contribute positively to data management and usage. Based on this idea, we have tried to outline an IoT infrastructure for preventive conservation of CHI collections, which exploits semantic web technologies for the organisation and management of recorded (sensors) and documented (conservation science professionals) data. Ontology entities and relations will facilitate the representation of (i) the sensor network itself, (ii) the sensor measurements/observations, (iii) the conservation data about objects documented condition state, pathology, original materials, applied/treatment materials, as well as, (iv) information about storage and exhibition suggestions and administrative information. Additionally, the use of ontology will allow the correlation between those data and the formulation of ontology-based rules.

To model conservation documented data as well as sensory data, which have derived from monitoring of temperature and relative humidity of objects environment, we suggest the combination of CIDOC CRM and SSN ontologies as a potential solution. Both these ontologies are top-level for the respective domains of CH and sensor networks, thus their combination and usage will ensure data interoperability. Furthermore, since CIDOC CRM is an extensible model, more special entities about scientific measurements can be used, while any addition of special entities/relations or usage of thesaurus will be facilitated. Particularly SSN entities and relations can be aligned with CIDOC CRM or/and its extensions. In this way, sensory data will be modelled using a standardised sensor ontology, while they will be meaningful in a special context: the sector of preservation of CH. For instance, the concept of Observation will be able to be perceived as a procedure to estimate the value of a property of a feature of interest, which is performed, by a Sensor, as well as an activity for measuring properties of physical phenomena related to a specific cultural Object.

Furthermore, the ontology-based representation of the data will allow the formulation of rules and production of inference information, useful for the system function and the presentation of recommendations for the users. Ontology-based rules will provide a better characterization of sensory data, not only defining what it is about (value, measurement of a physical parameter, place, time, related object) but also if there is a change according to a "set point", how important this change is and if it is related to potential risks, risk management plans or automate actions. Therefore, the system could provide (a) immediate notifications-alerts to the users about detected changes which will be prioritized according to the severity that they present, (b) automatically adjust temperature or humidity through actuators according to users settings and finally (c) provide documented information that has been stored in the CHI database to the users, which will be useful for them in terms of further object examination, treatment and handling.

3.2.   Architecture and Services

The proposed system extends any existing information systems of CHI by automating the procedure of collecting and reasoning sensory and conservation data. The architecture of the system depicted in Figure 1 is indicative of how the variable components are interconnected and which semantic languages and protocols are used. The core of the platform runs in Apache Jena, an open-source framework for semantic applications. Jena provides the API to read and write to RDF graphs, while supporting OWL and the more extended Jena rule syntax. Jena is also equipped with internal reasoners and rule engines that will provide semantically derived knowledge in real-time. The data can be distinguished in two categories: (a) conservation data, exhibition and storage suggestions and administrative information about the objects, (b) sensory data about the environment of exposure of the objects, which are collected from the sensors of the cultural ecosystem (IoT). All data is stored in the Triple Store based on the entities and relations of the ontology. The rules, either predefined or user-defined are formulated within the Rule Engine.
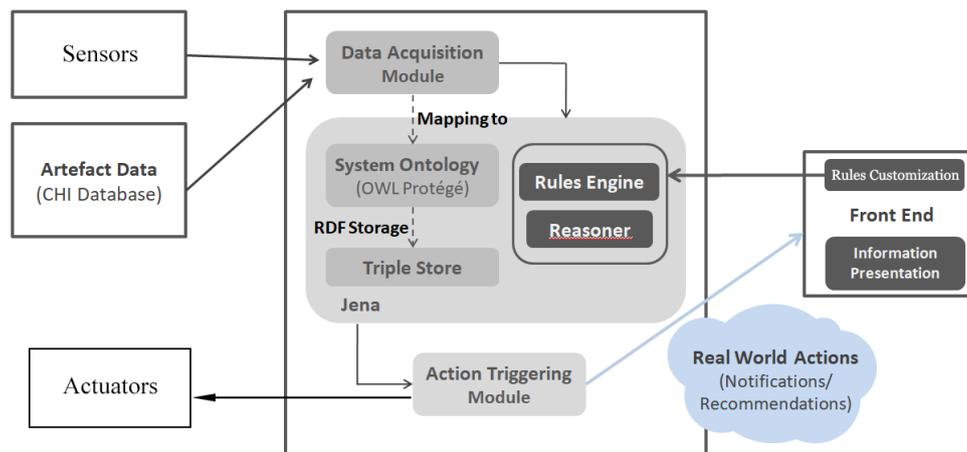

Figure 1: System Architecture

The language of input and output of Jena is RDF, a standard protocol for data exchange that allows data structured in triples to be shared between the exterior components and the core. Two modules (running Java Virtual Machines) are responsible for the connectivity of the system with the exterior ecosystem. The *Data Acquisition Module* is directly connected with the sources of data, mapping sensed and conservation data in RDF triples according to the Ontology Model and storing them in Triple Store. The module is responsible to collect the sensory data using the IoT infrastructure through appropriate gateways that will allow the connectivity of a seamless sensory network. The conservation and administrative data can be extracted from the CHI database, collected by appropriate API calls from an existing CHI system. The *Action Triggering Module* deals with the complications of notifying the designated curators/conservators for a predicted harmful situation, by transforming the RDF output of Jena into real world notifications (such as emails, SMS, etc).

The internal Jena reasoner is responsible for asserting possibly harmful environmental conditions based on semantic data stored in the Triple Store and the rules a priori formulated in the Rules Engine. The system output is mainly composed of notifications about those environmental changes according to their severity. Additionally, it will be able to provide information to users related to their potential actions and decisions based on interconnected semantic data about management plans, objects' features, place features, etc. Beyond that, visualization tools and a management interface are also needed to provide a better system flexibility and customization. Regarding the visualisation tool, it will provide diagrams about long-term sensory data, making them easier to perceived from the user and notice variation patterns though the time. The procedures are executed by the Front End component, which will be implemented in both mobile and web versions. Furthermore, the same component is used to give the possibility to the specialists an interface of defining their own rules that apply to their specific needs. The rules customization interface will allow the refinement of parameters of the Rules by the museum administration without requiring knowledge of semantic languages.

Preventive conservation services are not limited to alerts, visualization tools for long-term data measured environmental variables and retrieval/presentation of related documented information, but they can be further extended to automated preservation actions that either mitigate the effects of abnormal environmental conditions or customize the ecosystem to balance the requirements of the object and the visitors. In case of an existing IoT infrastructure that supports actuators along with sensors, the proposed system can connect to it and customize the environment according to the output of the Reasoner, communicated through the Action Triggering Module. The rules set a priori according to specific principles at the Rules Engine and the parameters set by the museum administration at the Rules Definition Module of the Front End determining the actions that need to be taken.

3.3. Sensors and Network

The technology behind sensing nodes is constantly evolving since WSNs are the backbone of many popular applications of the IoT paradigm (Razzaque, 2015). Bluetooth Low Energy (BLE) and IPv6 over Low power Wireless Personal Area Networks (6LOWPan) are among the most prominent protocols for WSNs which complemented by short distance protocols such as NFC and RFID can provide a holistic approach that will be adaptable to different

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topologies and geographies of Cultural Institutions. Lora Alliance is among the leaders at prototyping and providing out of the box sensor nodes (LoRa).

Since low power - and thus higher autonomy time - is a hard requirement, gateways are necessary to act as regional hubs that collect data from the WSN and distribute it to the main system, decreasing the maximum range of communication activity for the sensing nodes. Furthermore, gateways may act as middleware, masking variable protocols within the same WSN and allowing transcommunication inside the WSN in case of active sensor nodes. MQTT is widely used as the language of communication between sensor nodes and gateways, because of its low overhead and sensitivity towards CPU and bandwidth limitations (MQQT).

The proposed system although schematically independent of the WSN installed to the CHI, is reliant on the way the sensory data is transmitted. The Data Acquisition Module should not collect data directly from the nodes, but it requires the previously described scheme of gateways and nodes of varied communication protocols. Especially taking into consideration the limiting parameters of the geography of CHIs such as thick walls or wirelessly unavailable rooms and locations, the WSN needs to be installed ad hoc, providing gateways as the entry point of the preservation system.

4. Conclusions and Future Work

In this work, a review about implementations of sensors, sensor networks and IoT systems regarding the monitoring and control of indoor CHI spaces and historical buildings, has been conducted. Furthermore, we presented the application of semantic web technologies and more particularly ontologies for the representation and management of both sensory and cultural data focusing on the domain of CHI collections preventive conservation. As we have seen, there are several works about the implementation of dataloggers, wired and wireless sensors as well as WSNs, providing valuable data about objects environmental conditions through time. In the same context, we have presented some works about more complete IoT systems, which expand the possibilities of data collection, storage, processing and access. However, the use of ontologies has been partially discussed (Ayala et al, 2014), while its possibilities regarding data integration, management and reasoning in the IoT environment seems as not yet explored.

Considering that the development of an IoT infrastructure will be significantly beneficial for preventive conservation sector, as well as the exploitation of semantic web technologies for the facilitation of system's data management and services, we have described underlying technologies, architecture and services of a potential platform. The section of those two domains could benefit the performance and potentials of a complete IoT system and therefore enhance preventive conservation science approaches in museum collections.

Being in an early stage of our research, we have already identified two main technological challenges that the proposed infrastructure will need to address before being successfully deployed into a cultural institution's space. Firstly, it needs to be integrated with existing platforms, systems or networks of the CHI. The architectural scheme described in Section 3 requires a data flow with an existing database and the IoT sensor network, which is dependant on the connectivity capabilities and protocols of the predeployed infrastructure. This may not be the case when installing everything from scratch, but, in most cases, CHIs have some

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established systems that would prefer to use and integrate into the new ecosystem. The second challenge refers to the need for real-time reasoning and alerting which is critical for emergency cases. There is a hard cap on how quickly the Reasoner will act upon the collected data, which depends on the speed of the semantic reasoner and the complexity of the Rules and the Ontology.

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