An IoUT-Based Platform for Managing Underwater Cultural Heritage

Marta Plaza-Hernández(✉), Mahmoud Abbasi, and Yeray Mezquita

BISITE Research Group, University of Salamanca, Edificio Multiusos I+D+i, Calle Espejo 2, 37007 Salamanca, Spain
{martaplaza,yeraymm}@usal.es, Mahmoud.abbasi@ieee.org

Abstract. Conservation of Underwater Cultural Heritage is crucial to preserve society's history. This work proposes a platform based on Internet of Underwater Things technologies and the Edge Computing paradigm. It will incorporate Artificial Intelligence techniques that support the monitoring and management of Underwater Cultural Heritage. These algorithms and models, capable of generating knowledge, will work as a supporting tool for decision-making. The platform will integrate information stored in databases with data acquired in real-time, working independently and in collaboration with other platforms and systems.

Keywords: Underwater cultural heritage · Internet of underwater things · Artificial intelligence · Edge computing

1 Underwater Cultural Heritage: Threats and Challenges

As defined by the United Nations Educational, Scientific and Cultural Organization (UNESCO) in its 2001 Convention on the Protection of the Underwater Cultural Heritage (Art. 1.1(a)), "Underwater Cultural Heritage (UCH) means all traces of human existence having a cultural, historical or archaeological character which have been partially or totally underwater, periodically or continuously, for at least 100 years"; including (i) sites, structures, buildings, artefacts and human remains, together with their archaeological and natural context; (ii) vessels, aircraft, other vehicles or any part thereof, their cargo or other contents, together with their archaeological and natural context; and (iii) objects of prehistoric character [1].

The are many threats to UCH, including treasure hunting, pillage and commercial exploitation, trawling, irresponsible diving ("collecting souvenirs") and unsustainable tourism, resource extraction (sand, gravel, etc.), natural phenomena (earthquakes) and climate change [1]. The last is one of the most alarming issues. Three critical climate-related changes will affect UCH [2]. First, the increase in the surface water temperature will gradually spread to deeper layers, leading to chemical changes, which will provoke the deterioration of UCH. Second, the changes in the current patterns. Some experts predict that climate change could cause a possible interruption of the thermohaline circulation, primarily responsible for regulating the Earth's temperature. Such disruption will modify the sediment layer that preserves most UCH sites/items. Third, the rising

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sea level could directly impact not only coastal but also underwater heritage. Some land-based sites will flood. Additionally, extreme weather events (tropical storms, hurricanes, cyclones, etc.) will erode land and underwater heritage [2].

The conservation and restoration of UCH require complete knowledge of the environment in which an item/site is located, the materials from which it is made, and the degradation phenomena experienced in the surrounding environment, which may be physico-chemical (seawater), biological (living organisms), geological (type of substrates and sediments) or human-made [3]. Protection and conservation methods and processes, from the evaluation and analysis of the state of the heritage to restoration activities, still present multiple challenges [4]:

- lack of knowledge and techniques suitable for underwater in situ conservation and protection;
- the elevated costs and the complexity of operating underwater;
- lack of regulation (planning policies, methods, tools, and resources);
- ineffective protection of items/sites and inability to use them for sustainable and responsible tourism development;
- lack of policies and resources to cope with the effects of climate change.

To overcome most of these obstacles, the UNESCO created a treaty, *The Convention on the Protection of Underwater Cultural Heritage 2001* [5], which establishes basic principles for protection, rules for heritage treatment and a system of international cooperation. So far, only 63 countries have ratified or accepted this document.

This work proposes a platform based on the Internet of Underwater Things technologies and the Edge Computing paradigm. It will incorporate Artificial Intelligence techniques that support the monitoring and management of UCH. These algorithms and models, capable of generating knowledge, will work as a supporting tool for decision-making. The rest of the paper is organised as follows: Sect. 2 introduces a sustainable solution for the conservation of UCH, Sect. 3 presents the proposed IoUT-based platform, and Sect. 4 draws the main conclusions and describes future lines of research.

2 A Sustainable Solution for the Conservation of Underwater Cultural Heritage

The conservation of submerged archaeological complexes requires the adoption of innovative and sustainable solutions that aim not only to preserve them in-situ but also to use the available information for decision-making. With the current availability of an enormous amount of data, the challenge is to identify intelligent and adaptive ways of combining the information to create valuable knowledge [6].

The use of sensors could be one of the most cost-effective practices for assessing the state of tangible heritage, facilitating the monitoring of environmental changes. The Internet of Things (IoT) refers to the connection of multiple and heterogeneous objects with electronic devices through different communications to collect and provide data [7–11]. This new technology has grown rapidly, finding applications in multiple sectors such as energy efficiency, health care, industry 4.0, security and public protection logistics and transport, etc. The conservation of UCH can be improved by using efficient and monitoring control systems [12]. On the one hand, preventive conservation is crucial to control the deterioration/decay phenomena of items and sites [13]. To ensure preventive conservation, environmental variables should be long-term monitored and predicted with enough time to react, performing data analytics to detect patterns and dangerous oscillations [14]. On the other hand, long-term monitoring and predictive maintenance can mitigate the damage and reduce future restoration costs [13].

3 An Intelligent Platform for the Management of Underwater Cultural Heritage

Wireless Sensor Network (WSN) plays a key role in IoT. It consists of many distributed sensors interconnected through wireless links for physical and environmental monitoring purposes [15]. The concept of IoT adapted to marine environments is known as the Internet of Underwater Things (IoUT), defined as “the network of smart interconnected underwater objects”, such as different types of underwater sensors, autonomous vehicles, buoys, ships, etc. [15, 16]. To support the IoUT, the Underwater Wireless Sensor Networks (UWSN) are considered a promising network system [17, 18]. Since the technologies of communication and waterproofing of equipment are in a mature phase, it is an appropriate time to investigate this field.

Sensors are nodes with acoustic modems distributed in either shallow or deep water. Each sensor node can measure, relay, and forward data. Information is sent through acoustic channels to the components on the surface, called sinks, which are nodes with both acoustic and radio modems [19]. When data arrive at sinks, they will forward it to the remote monitoring centre through radio channels [17]. The sensor nodes, either fixed or mobile, are used to respond to changes in their environments. Physical sensors measure different parameters like temperature, humidity, pressure, etc. Chemical sensors measure parameters like salinity, turbidity, pH, nitrate, chlorophyll, and dissolved oxygen, etc. [20]. Autonomous Underwater Vehicles (AUV) are fitted with sonar sensors for assisted navigation and are equipped with selected sensors that collect data from the surveyed environment [21–24]. Underwater sensors and AUVs cooperate in sophisticated tasks such as large-scale, long-term perception of the environment and reaction to environmental changes [21, 22].

Typically, multiple wireless communication technologies are used in IoUT-based marine environment systems. Underwater acoustic communication technologies are used for data collection and communication among underwater marine environment sensors [25, 26]. Generally, longer-range communication consumes more energy. The selection of the most appropriate wireless communication technology for an application depends on the transmitted data volume, transmission frequency, transmission distance, and available power supply. Nevertheless, significant progress has already been made [15]. Different wireless communication standards and technologies have been developed and tested, including WiFi (range < 100 m), Bluetooth (range 1–100 m), GPRS (dependent on the service provider), ZigBee (range < 75 m) and WiMAX (range < 10 km). A summary and comparison of them can be found in [20].

This work proposes a platform based on IoUT technologies and the Edge Computing paradigm. It will incorporate AI techniques that support the monitoring and management of UCH. These algorithms and models, capable of generating knowledge, will work as a supporting tool for decision-making. The Edge Computing paradigm brings computation and data storage closer to the location where it is required. Its main objective is to solve congestion and bottlenecks in the processing and communication levels, bringing computer resources and services closer to the end-user and the deployed devices [27–30]. The platform will integrate information stored in databases with data acquired in real-time. The proposed platform will work independently and in collaboration with other platforms and systems. IoUT systems part of the proposed platform will be used for:

- monitor and control the heritage's environmental and material conditions to optimally preserve them, detecting structural changes in materials;
- environmental monitoring, including water quality, chemical and biological pollution, thermal pollution, pressure, temperature, pH, salinity, biological growth, conductivity, marine currents, disaster prevention, etc.
- alert of an anomalous event.

Among the main functionalities of the platform, we emphasise the capability to record physical and chemical parameters and transmit the information wirelessly and encrypted. At the sensors level, the proposed architecture will be able to deal with high energy constraints and support fast-changing environments. It will provide elasticity at the storage level and facilitate access to data visualisation.

3.1 A Layered-Based Architecture

Through the platform modules, the control of the different components will be performed by developing a layered architecture. This architecture allows an incremental development of application and service management, and it includes three layers (Fig. 1).

The *perception layer* includes the IoUT sensor and actuator devices, with the objective of sensor data collection and command actuation, surface stations (sinks) and data storage tags [31]. The *network layer* is made of edge nodes, liable for data processing, functioning as data collectors, providing computing, storage, network and other infrastructure resources. This layer allows access of the sink over the sea to the radio channel to process and transmit the information obtained from the perception layer. This information is retransmitted to the onshore centre using different access networking technologies [19, 21]. The *application layer* includes multiple cloud services responsible for data analysis and visualisation, employed for big data analysis and data mining, it is the key where models are performed with AI methodologies from the data uploaded by the edge equipment [11, 21, 32–34].

3.2 Data Stages

The data will combine real-time data collected by the IoUT sensors and information from public databases. The sensors will measure the key environmental factors that participate

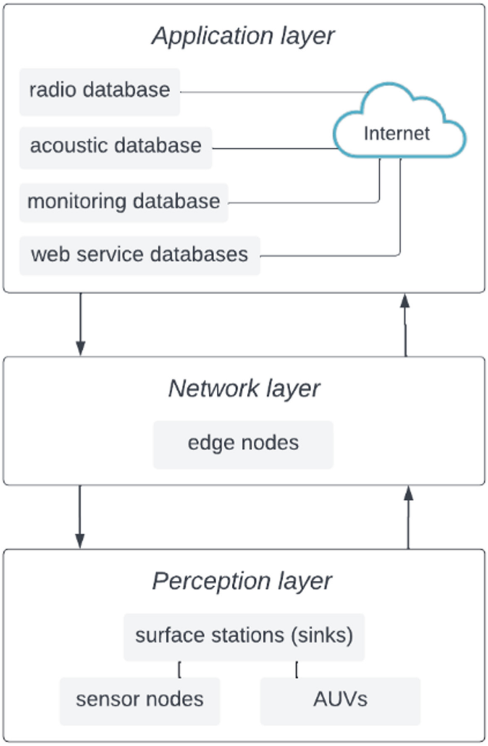

Fig. 1. Proposed architecture. Adapted from [22].

in the degradation phenomena of UCH: temperature, pH, salinity, conductivity, marine currents, biological growth or chemical pollution, especially for those UCH items that are close to the coast. Real-time images will also be collected to show degradation over time and for the monitoring of UCH after the application of the restoration treatments. Information from public databases will include a description of the item (physicochemical properties, age, etc.), the previous restoration works in place, and historical data on key environmental factors.

With this data we aim to:

- describe the current state of UCH, and study the environment in which it is located, so that conservation approaches can be applied;
- make predictions on how degradation phenomena will affect UCH in a changing environment.

The different stages of the data are displayed in Fig. 2. For the pre-processing stage, information will be extracted and transform into a comprehensible structure for further use. Some data mining tools useful for this stage are WEKA, SPSS or KNIME. Later, AI algorithms will be used to quantify UCH degradation phenomena (predictions). The algorithms selected will depend on the data. Several examples of supervised algorithms are classification (decision trees), regression (linear regression), neural networks (non-linear regression). Also, Convolutional Neural Network for images. And lastly, the visualisation of the data so local authorities, public and private organisations and the public can make sustainable decisions regarding UCH.

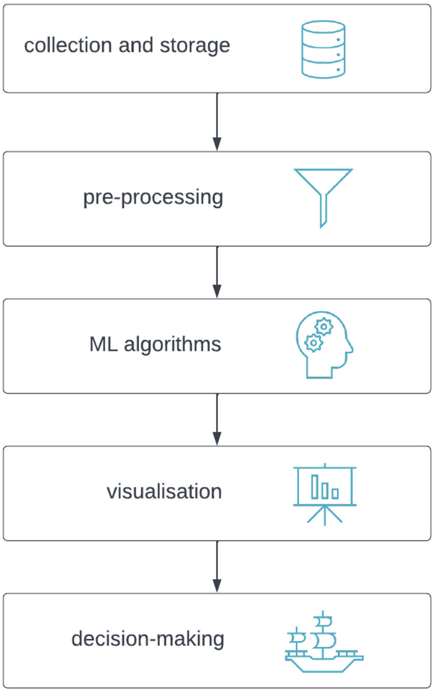

Fig. 2. Proposed data stages.

3.3 Main Challenges

See Table 1.

Table 1. Main challenges of the proposed platform.

Transmision media	UWSNs rely on acoustic communications instead of radio communications because radio signals are absorbed by water quickly. Unfortunately, the communication protocols applied to terrestrial networks cannot be directly applied to acoustic waves [17]
Propagation speed	The propagation speed of UWSN acoustic channels is 1500 m/s [32]; 200,000 times slower than terrestrial networks

(*continued*)

Table 1. (*continued*)

Transmission range	To avoid being absorbed by water, signals need to be transmitted using low frequency. However, lower frequency implies a longer transmission range, with interferences and collisions possibly happening [17]
Transmission rate	Acoustic communications in UWSNs use a narrow bandwidth, so that the transmission rate in UWSNs is generally very low [17]
Difficulty to recharge	Since sensors are deployed underwater, it is challenging and high-priced to recharge their batteries [35]
Energy efficiency	To make the sensor nodes operate for long periods of time, energy efficient algorithms specially designed for IoUT are needed [32, 36]
Mobility	The sensor nodes move and suffer from dynamic network topology changes, impacted by water currents repeatedly. Still, sensor nodes are able to respond to changes in their environments
Locatisation	There are several challenges in complying with the localisation requirements posed by UWSNs [37]. First, the tight time synchronisation between the transmitter and the receiver clocks [38]. Second, the speed of sound cannot be assumed constant (as in the terrestrial localisation schemes); it is a function of temperature, salinity and depth. Third, the multipath effects due to surface reflection, bottom reflection and backscattering [39]
Reliability	The reliability of a link indicates the successful delivery ratio between a pair of sensor nodes. In UWSNs, this ratio would be affected by transmission loss (signals are absorbed by water) and environmental noise. Low reliability leads to frequent data retransmission, resulting in longer delay and higher bandwidth consumption [17, 40]
Lack of standarisation	The development of novel protocols for IoUT is required to provide interoperability between heterogeneous underwater objects [32, 41]
Confidentiality	It refers to protecting information from unauthorised access and preserving the IoUT devices and actuators. Confidentiality is challenging due to the high number of devices involved [42, 43]
Integrity	It refers to data consistency, accuracy, and validity over workflow [44, 45]. In IoUT systems, integrity can safeguard the system against the unapproved spread or modification of information [46]
Availability	It guarantees that service and network will stay operating even in the condition of faults or malicious activities. Availability needs security and a fault management process [47]

4 Conclusions and Future Work

The documentation and conservation of UCH are crucial to preserving society's identity and memory, securing its accessibility to current and future generations. This work proposes a platform based on IoUT technologies and the Edge Computing paradigm. It will incorporate AI techniques that support the monitoring and management of UCH. These algorithms and models, capable of generating knowledge, will work as a supporting tool for decision-making. The platform will integrate information stored in databases with data acquired in real-time. The platform will be able to work independently and/or in collaboration with other existing platforms and systems. Future work includes the implementation and validation of the platform presented in a simulated scenario, where tests can be run.

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