



Proceeding Paper

Microclimate Monitoring Using Wireless Sensors for the Conservation of Cultural Heritage: The Case of the Holy Cross Hermitage in Olympus Area, Greece [†]

Christiana Papitsi, Theodore Ganetsos * , Meropi Katsantoni, Christos Drosos and Eleni Symeonaki

Department of Industrial Design and Production Engineering, University of West Attica, 12244 Egaleo, Greece; xpapitsi@gmail.com (C.P.); m.katsantoni@uniwa.gr (M.K.); drososx@uniwa.gr (C.D.); esimeon@uniwa.gr (E.S.)

* Correspondence: ganetsos@uniwa.gr

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Abstract: This work presents an approach for wirelessly monitoring the indoor temperature, relative humidity, and carbon dioxide (CO₂) concentration parameters affecting the microclimate of the Holy Cross hermitage, which extends into a small cave located in the Olympus area of Greece and maintains remarkable wall paintings dated back to 1339 A.D. The results indicate that the methodology applied was effective enough in maintaining a long-term monitoring process and, as a result, comprehending the ambient conditions of the hermitage with regard to its microclimate. In this context, it would be possible to identify any imminent hazards in time and therefore plan the required conservation actions.

Keywords: cultural heritage; wireless sensors; monitoring; microclimate; temperature; humidity; carbon dioxide



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1. Introduction

Cultural heritage sites and their historical relics are endangered due to climate change, which affects inadequate microclimatic factors [1], such as temperature, relative humidity, and CO₂ density [2]. In this context, long-term historical records of these parameters can be useful in analysing the overall conditions and studying the role of the environment in the deterioration of cultural heritage [3], making microclimate monitoring an important aspect of cultural heritage conservation [4]. Nevertheless, monitoring microclimate parameters remains challenging for many distant cultural heritage sites due to a lack of power supply and network access [5].

Wireless sensor technology is quite appealing for this purpose [6], since one of its main benefits is that the wireless nodes require much less power consumption for their operation, allowing the devices to be battery powered [7]. In addition, wireless sensor nodes are small, portable, and can be placed in hard-to-reach as well as discreet positions to avoid interfering with the aesthetics of the cultural heritage sites [8], while at the same time they can monitor constant data on microclimatic conditions that can be used to identify trends and patterns leading to informed decision-making regarding conservation actions [9].

To this end, this work presents an approach for monitoring the parameters affecting the microclimate of the “Holy Cross” hermitage, which extends into a small cave located on the southern slope of the Kastri Hill in the Olympus area in Greece and maintains remarkable frescoes dated back to 1339 AD [10]. In particular, the methodology applied to perform the monitoring process is described, considering the location and structure of the hermitage. Based on this, a wireless sensor node was installed according to the most substantial and accessible points in the hermitage for the constant monitoring of the indoor temperature, relative humidity, and carbon dioxide (CO₂) concentration. The raw sensory data are

digitally acquired in order to provide a long-term historical record for comprehending the environmental conditions of the hermitage with regard to its microclimate. In this context, it would be possible to identify any imminent hazards in time and therefore plan the required conservation actions.

The remainder of the paper is organised as follows: The first part of Section 2 overviews the history of the place of study, that is, the “Holy Cross” hermitage in the Olympus area of Greece, and provides some useful information regarding the structure of its premises, while in the second part the process of monitoring its microclimate parameters is described. Section 3 presents the results of our deployment. Finally, Section 4 discusses the validation of this study and derives some useful conclusions, while perspectives on future directions are also pointed out.

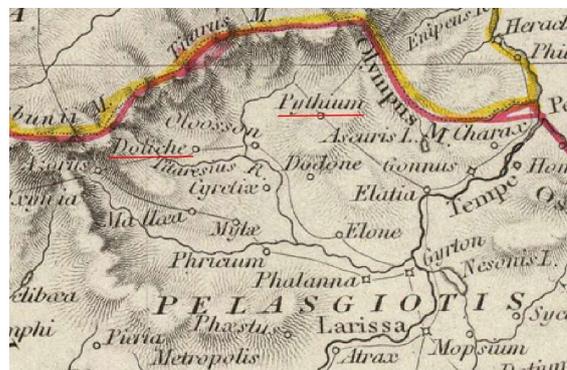
2. Materials and Methods

2.1. Place of Study

Pythion is located on the western foothills of Mount Olympus, at an altitude of about 650m (Figure 1a). The ancient city of Pythion was located in the same place, with the cities of Dolichi and Azoro forming the Perrheabian Tripoli, which extended into the hilly area north of Elassona and was bordered to the north by the mountains Olympus, Titarus, and Kamvounia (Figure 1b). It also flowed by the river Titaresius and communicated with Macedonia through the Petra and Sarantaporos straits. In Byzantine times, the city moved to a new, more fortified location on the “Kastri” hill. At the top of the hill, part of the fortified enclosure of the citadel (acropolis) and building remains are preserved up to the present time, indicating the continuous inhabitation of Pythion during the Byzantine period. In the 14th century, the “Kastri” hill served as a refuge for hermits. The best preserved hermitages are located on the southern slope of the hill, with the hermitage of “Ascension” at its foot and the “Holy Cross” one slightly higher above.



(a)



(b)

Figure 1. (a) Pythion Hermitages location on a contemporary map; (b) The Perrheabian Tripoli area.

The “Holy Cross” hermitage, in particular, extends in a small cave and on the narrow platform formed by the rock in front of it (Figure 2a). It consists of three chambers: the chapel inside the cave, the narthex, and the hermit’s cell on the platform. The last two halls were covered by a single wooden roof, which had been destroyed. The entire structure does not closely follow a certain type of temple but is rather formed according to the rock and vertical walls.

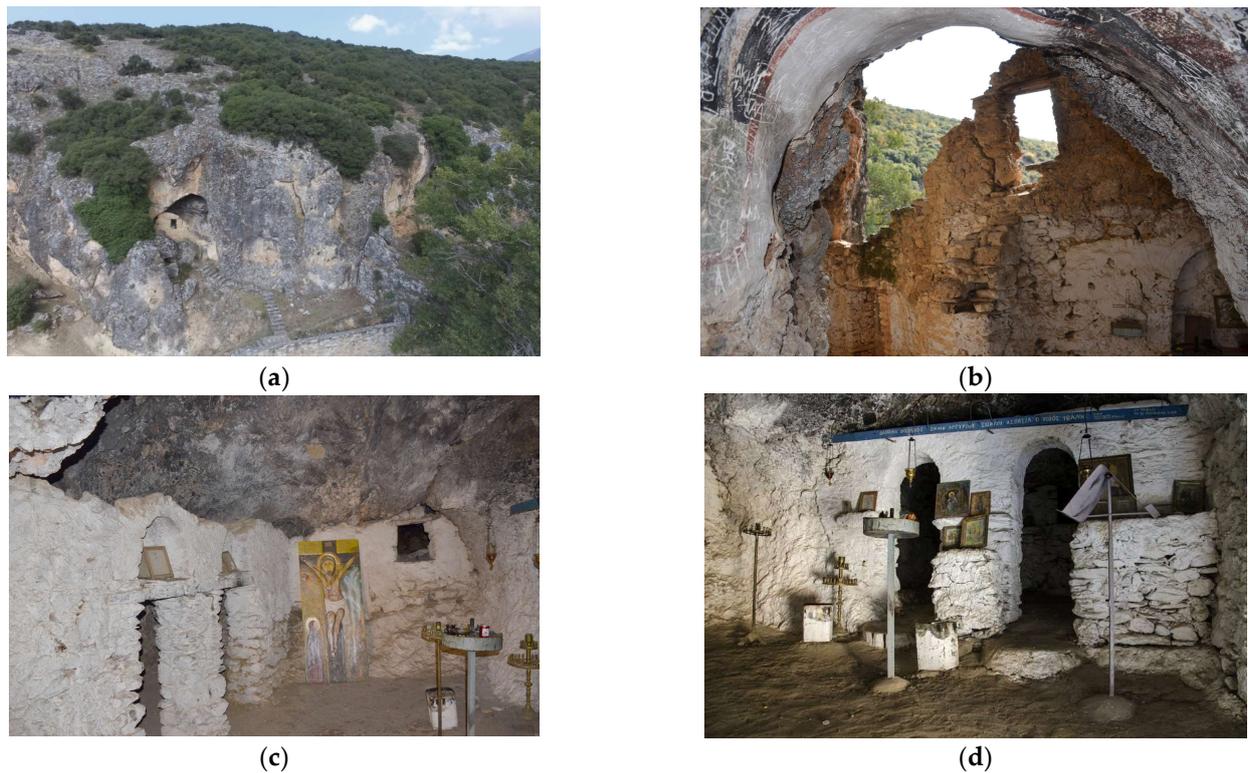


Figure 2. The “Holy Cross” hermitage. (a) Exterior view and (b) interior view of the narthex. (c) Interior view of the sanctuary. (d) Interior view of the chapel.

In more detail, the first hall, which constitutes the narthex, is located to the south-west, with its entrance oriented to the west (Figure 2b). Two openings on the north and east sides communicate with the chapel and a continuous platform space. The floor plan is square in shape, with dimensions of 2.24×2.08 m. The second hall, which served as the hermit’s cell, measures 2×1.85 m and communicates only with the narthex. Both the narthex and the cell retain intact their eastern side, most of which is the natural rock itself. Its covering, as the traces show, was made by a single pitched wooden roof. The chapel (Figure 2c) is placed at a lower level than the narthex (0.40 m) and is connected by a small step used for passage. Its plan is in irregular trapezoidal form, with straight and curved sides ranging from 1.30 m to 2.85 m long, while the floor is paved with cinder blocks. It has a terrace to the south-east and a blind arch to the north-west. The chapel’s sanctuary (Figure 2d) is placed on the northeast side, in the opening (1.27 m wide) of which there is a wooden beam, where rests a wall with a blind arch on the main front. The sanctuary terminates in a semicircular niche to the north-east, while a second one is on the north-west wall, serving as a projection. The floor plan of the sanctuary is almost rectangular in shape, measuring approximately 0.86×1.17 m. All the vertical walls of the chapel are adjacent to the walls of the cave, while the natural rock itself serves as a superstructure, gilded with thick mortar to create a suitable surface for frescoes. The walls are 0.60 m thick and made of roughly carved limestone and rocks, as well as of 0.025 to 0.03 m thick cinder blocks.

The premises of the “Holy Cross” hermitage are of particular interest as they preserve remarkable frescoes of saints and hierarchs at the lower level as well as scenes from the life of Christ in the higher parts and on the ceiling. The foundation and the frescoes of the “Holy Cross” hermitage date back to 1339 AD (according to the inscription above the entrance to the sanctuary), that is, during the reign of Emperor Andronicus III Palaiologos and his wife Anna [10].

2.2. Application of Wireless Sensors for the Monitoring Process

The goal of this study is to closely monitor and analyse changes in the temperature, relative humidity, and carbon dioxide (CO₂) concentration parameters inside the “Holy Cross” hermitage so as to avoid unfavourable environmental conditions that can negatively affect the microclimate of its premises, causing deterioration and damage to the relics. For the deployment of the wireless node, the structural specifications of the “Holy Cross” hermitage premises (as detailed in Section 2.1) were therefore taken into consideration.

In this context, a cost-effective, small-sized (61 × 93 × 53 mm) and lightweight (250 g) wireless node, suitable for places where there is no rapid change in temperature or relative humidity, was deployed for conducting non-invasive measurements. The node (Figure 3) is equipped with internal sensors for monitoring temperature, humidity, and CO₂ parameters. The measurements are performed with a 1 s interval, and the measured values are constantly shown on the device’s LCD display. Since there are strong limitations regarding the lack of power supply and network access at this phase of the study, the node is also equipped with a rechargeable Li-ion battery (5200 mAh) and a data logger that records in a non-volatile electronic memory the measured values of the corresponding parameters. The recorder includes a traceable calibration certificate with declared metrological traceability of etalons based on the requirements of the EN ISO/IEC 17,025 standard. The recorded data can be transferred via USB-C, allowing for long-term historical records of the parameters of interest. Finally, in the event of exceeding set limits, alarms may be indicated by LED, LCD, or acoustically by the built-in beeper. Some additional interesting technical data regarding the sensors is reviewed in Table 1.

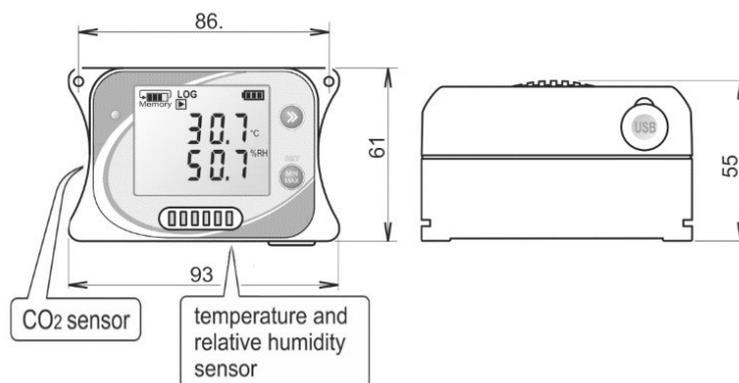


Figure 3. Wireless node deployed in the “Holy Cross” hermitage.

Table 1. Technical data of the sensors included in the wireless node.

Measured Parameter	Range	Accuracy	Response Time	Display Resolution
Temperature	−20 to +60 °C	±0.4 °C	t63 < 2 min	0.1 °C
Relative Humidity	0 to 100% RH	±1.8% RH	t63 < 45 s	0.1% RH
CO ₂ Concentration	0 to 5000 ppm	±(50 ppm +3% from reading) at 25 °C and 1013 hPa	2 min/10 min	1 ppm

3. Results

Measurements were carried out in the “Holy Cross” hermitage during the period from 15 January 2023, until 13 March 2023. Such a measurement period allowed the observation of the rate of changes in recorded parameters in the interior of the hermitage for validation purposes. The metres recorded the temperature, relative humidity, and CO₂ concentration with a one-minute time step during each day, producing a record of 82,122 values for each monitored parameter of interest. The variation range (min and max) and the mean of the monthly monitored values per parameter are presented in Table 2, while in Figure 4, the representation of the wireless data values is depicted for each one of the monitored parameters.

Table 2. Wirelessly measured values in the “Holy Cross” hermitage.

Month	Temperature (°C)			Relative Humidity (%RH)			CO ₂ Concentration (ppm)		
	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean
January 2023	8.239	14.946	10.616	34.515	60.693	54.169	385.000	921.000	430.000
February 2023	5.047	11.693	8.813	24.487	65.112	42.157	388.000	563.000	432.000
March 2023	9.830	12.711	10.797	41.931	68.103	61.188	399.000	620.000	440.000

Measurement period: from 15 January 2023 to 13 March 2023.

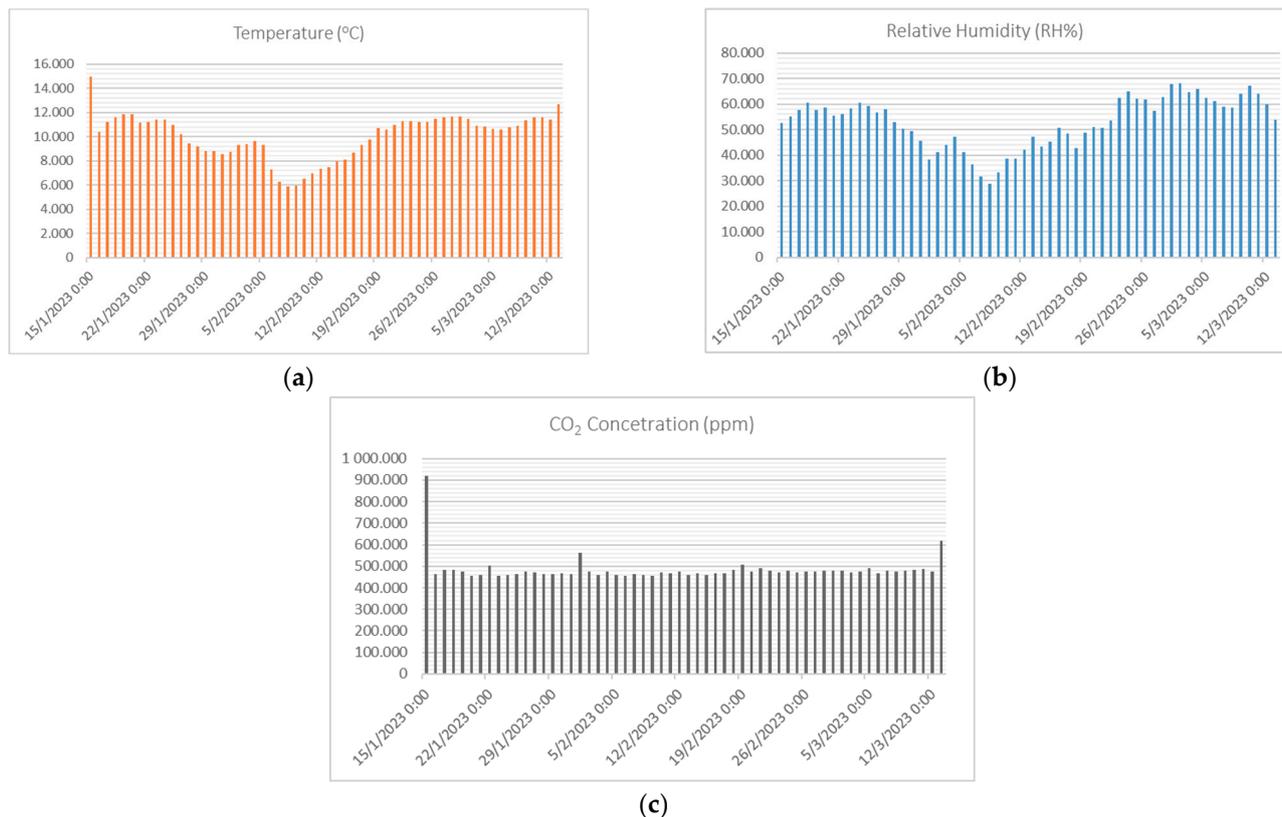


Figure 4. Wireless data values: (a) temperature (°C); (b) relative humidity (RH%); and (c) CO₂ concentration (ppm).

4. Discussion and Conclusions

This work presented an approach for wirelessly monitoring the temperature, relative humidity, and CO₂ parameters affecting the microclimate of the “Holy Cross” hermitage located in a small cave on the southern slope of the Kastro Hill in the Olympus area of Greece, which maintains remarkable frescoes dating back to 1339 AD. As indicated by the results, the methodology applied was quite effective in maintaining a long-term monitoring process and, as a result, comprehending the ambient conditions in the interior of the hermitage with regard to its microclimate. In this context, it would be possible to identify any imminent hazards in time and therefore plan the required conservation actions.

The future directions of this work are oriented towards the deployment of a wireless sensor network (WSN) using 5G or the LoRaWAN communication protocol in order to achieve real-time cloud-based monitoring and management of the sensory data regarding the microclimate conditions of the “Holy” Cross hermitage.

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preparation, C.P., M.K. and E.S.; writing—review and editing, C.P. and E.S.; visualisation, M.K. and E.S.; supervision, T.G.; project administration, T.G.; funding acquisition, T.G. and M.K. All authors have read and agreed to the published version of the manuscript.

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