Journal of Cleaner Production 142 (2017) 2707–2721

Contents lists available at ScienceDirect

Journal of Cleaner Production

journal homepage: www.elsevier.com/locate/jclepro

A real-time underground environment monitoring system for sustainable tourism of caves

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ARTICLE INFO

Article history:
Received 6 July 2016
Received in revised form
4 October 2016
Accepted 1 November 2016
Available online 3 November 2016

Keywords:
Cave
Environment measures
Real time
Telecontrol
Sustainable tourism

ABSTRACT

In this paper, a real-time monitoring system is presented to be used for environmental parameters measurement in tourist caves that can be employed for getting a sustainable tourism. The system allows the registration of a lot of metadata (temperature, relative humidity, wind speed and direction, CO2, atmospheric pressure, rain, presence and visitor count) and it shows them via the Internet in real time anywhere. The system reports the data registered and stored as metadata in a database online. In the "El Soplao" Cave in the North of Spain, this system, permits a high level of control and security of the influence of visitors on a day to day and the temporal evolution to medium and long term. These measurements allow developing a sustainable and profitable system where heritage management and tourism exploitation acquire a subordinate commitment to the welfare of the natural asset (Cave-Mine "El Soplao"); the alteration of the fragile microclimate inside the cave can damage or destroy the specific geologic formations that make the touristic cave. After the visits, the company managing the cave takes in charge monitoring the environmental parameters of the cave to regulate future visits. The temperature in the cave has ranges between 11 and 13.5 °C, a seasonal quasi-periodic maximum variation of ± 0.5 °C and depending on the temperature outside the cave and number of visitors; it is difficult to associate one with another because both happen in the same month. The relative humidity is around 70–95%, it has no correlation with the number of visitors accessing the cavity. The CO2 concentration in air is around 400–1000 ppm; it has a clear correlation with the number of visitors and cave area (the deepest present's higher level CO2). In conclusion, a cave is visited as long as its microclimate is maintained, thus the real-time system developed has been conceptualized for monitoring over time the relationship between the cave environment and a sustainable tourism. Monitoring can help to preserve the specific geologic formation and therefore to keep the touristic interest of the cave.

1. Introduction

The caves have been used for thousands of years for different purposes. However, people have realized the recreational, aesthetic and scientific value of caves only recently. In the early seventeenth, the opening of the Vilenica Cave in Slovenia for tourist visitors by paying has enlightened the recreational use of natural caves. Since 1816, a number of caves worldwide were being regularly visited. The number of show caves has increased significantly in the second half of the nineteenth century to reach more than 600 worldwide today.

According to Gillieson (2009), all the countries of the world in present hold at least one, but often show dozens of caves. There exist about 500 major show caves with more than 50,000 visitors per year, about 250 million visitors who pay a ticket yearly to visit these caves. By considering all the activities related to the existence of show caves (transportation, lodging, etc …), it can be stated that about 100 million peoples rely in their income directly or indirectly from show caves. Therefore, the most important geotouristic target all over the world is represented by show caves, an essential economic resource for many of the still developing countries. Due to the fact that they represent the best archive for all the

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http://dx.doi.org/10.1016/j.jclepro.2016.11.005
0959-6526/

Quaternary and allow for extremely accurate paleo-environmental and paleo-climatic reconstructions, caves, as truly fragile environments, have an exceptional scientific value which can be easily destroyed when the cave becomes a touristic object. Therefore it is important to follow strict rules, before, during and after the touristic development in order to maintain the aesthetic and scientific values of cave when transformed to a show cave (Cigna and Forti, 2013). In long-term protecting of the areas of high geodiversity and biodiversity in nature conservation, the progress has been limited and higher priority has been given to economic development. However, the natural values are in an increasing risk if the nature conservation will not be properly integrated into programs intended to enhance economic and social development. Developing policies for sustainable development in the short and long term is a must. The effective tools management of natural sites can be monitored specifically by these vulnerable systems.

Overall, providing professional supervision, ensuring the sustainable development of the cave system to implement guidelines of using the cave system as natural asset and carrying out climatic and biological monitoring of the cave consist the essential missions of those involved in the cave adviser role (Šebela and Turk, 2014).

There is a growing support among policy makers. Researchers involved in ecological modernization (Jones, 2010), clean technology and eco-innovation are key to creating a win yet maintain and/or improve the economy's competitiveness insurance and environmental sustainability of the different sectors and the economy as a whole. Studies on the benefits of a regulatory policy environment improve competitiveness and sustainability at the level of sectoral systems, technological systems or social functions. There are a variety of factors that positively influence the voluntary environmental management, where regulatory pressures are among the most important (Jones, 2010; Coenen and Díaz López, 2010).

In order to ensure that there is no deviation outside acceptable limits, it is necessary to monitor the relevant parameters after the environmental impact evaluation of the development. A monitoring network of the cave environment should be maintained to ensure that it remains within acceptable limits (Cigna and Forti, 2013).

There are examples of studies on the microclimatic in Caves with the aim of recognizing the potential influences of tourist use on the cave (Šebela and Turk, 2011; Santos Lobo et al., 2013). The plan for climatic monitoring includes routine recording of basic parameters as air temperature, air pressure, CO2, wind and relative humidity (RH) but also places emphasis on the need to analyze the impact of outside climate on the cave interior. Among the environmental parameters mentioned, the most significant are CO2, humidity and temperature considered as indicators of a good cave health. The geological formation of the cave depends on its microclimate; it can be affected naturally by the existence of inflow of air due to the multiple entrances. Another influence should be taken into account and is illustrated by the human presence in the cave. Natural influences can produce a specific microclimate that results in a geological characteristic formation of the cave where the essence of touristic interest resides and its alteration is hard to control. However, artificial influence may alter negatively the cave up to its destruction. Previous studies indicate the limitations of these natural parameters for each cave without visits. Analyzing the changes in cave microclimate related to increased use of the cave for tourism is the goal of climatic monitoring. This permits limiting the number of visitants including reducing drastically the cave touristic visits for recuperating its health, as happened in 2002, where the “Altamira Cave” had to close its touristic visits till 2014 to be recuperated. The re-opening has been made to reduce the number of visitants with a strict control over the internal environmental parameters to avoid its closure once more (Sanchez-Moral et al., 2014).

In the context of the international significance of sustainable management of caves, predictive analyses covering potential cases of tourism growth in “El Soplao” Cave and its influence on the cave's microclimate are considered (Gázquez et al., 2010). Recent technological developments in the areas of electronics and communication technologies have enhanced the appearance of networks of environmental sensors. These networks allow environmental monitoring using an array of small sensor networks or the interconnection of networks where large heterogeneous (ad-hoc) wireless and wired networks are involved. Proper use of the type of network, media and necessary structure depends on the characteristics of the nodes, the coverage and enforcement. The network infrastructure combined with environmental sensors enables the collection and analysis of data from small to global scale. Collaboration among earth scientists and engineers is making large global projects possible. As an example in 1986, the Incorporated Research Institute for Seismology (IRIS) established the Global Network Consisting of 136 seismographic stations propagated in 59 Countries across the globe (Butler et al., 2004).

In (Hart and Martinez, 2006) are presented examples of networks multiplex sensors of different coverages and applications developed to serve the study and environmental analysis. In (Cama et al., 2013) is described the largest permanent wireless network with a coverage of 450 Km within the Peruvian Amazon rainforest to analyze the climate change impact. The wireless network is for the continuous monitoring of the environmental parameters such as humidity, temperature, total solar radiation, photosynthetically active radiation, and soil moisture in the Amazon.

These technologies have changed the vision of scientists studying the earth and environmental sciences, allowing them to work from office where they face the evaluation of huge amounts of data collected. This allows them to give a new approach to study the environment, new methods and to apply new advanced solutions to scientific problems.

The sustainable tourism emerged in the late 1980s and has become firmly established in both tourism policies and strategies and tourism research (Budeanu et al., 2016). Despite several decades of academic and practical debate on tourism sustainability, its application in practice remains difficult (Mihalic, 2016). Some studies focus on the discursive and practical tension between ambitions for development and maintenance of sustainable tourism (Hultman and Säwe, 2016). In Spain some examples are highlighted in the literature, where an enormous environmental pressure from conventional and massive tourism is made in the Balearic Islands (Fortuny et al., 2008). Then it is important to identify the environmental barriers during the planning process of sustainable tourism development (Hatipoglu et al., 2016). The conflict between tourism and heritage management on the one hand and a focus on economic return on the other (Gillieson, 2011) must take a subordinate role to the well-being of Cave as a natural asset.

Due to the largely spectacular formations of the mine-cave “El Soplao” a major tourist attraction is offered (Gázquez et al., 2003). This cave-mine receives an average of 200,000 visitors a year since it was opened to public after completion of the cave preparation for tourist exploitation in early 2007. The telemetry in real time can control the change of the environmental parameters in the cave with presence of visits and the company charged of maintaining it can limit the permitted number of visits daily in function of the obtained values. For example, for the cave of Kart in Yeso of Almeria (Guillén et al., 2006), the companies charged of organizing the visits revise the parameters after each visit to pursue new visits or cancel them until the recuperation of its specific range of environmental parameters values. The company managing “The

Soplao" Cave touristic sights taked into account increasing or decreasing the number of visitants according with the obtained values from telemetry before the following visit.

The objective of this manuscript is to develop a real-time monitoring system for studying the environmental impact of visits for the sustainable exploitation without harming the natural underground environment.

2. Site description

The Cave Mina "El Soplao" is a wonder of nature that is located in the province of Cantabria. "The Soplao" Cave (43°17′45.42″N – 4°25′45.76″ W) is located in the Sierra of Arnero, in the mountain range Shield of Cabuérniga (Cantabria, Northern Spain). The Sierra of Arnero mountain chain runs parallel to the Cantabrian Coast, Bustriguado between the valleys and Nansa (municipal districts of Valdáliga, Rionansa and Herrerías), see Fig. 1.

The cave entrance is 540 m a.s.l. and extends over 22,600 km, with barely 50 m variation in altitude. The total length of the cave, including the mining galleries, is approximately 52,600 km. Due to the significant increase in the cave development; new galleries have recently been discovered. The cave passages are oriented mainly NW-SE, with a secondary axis along NE-SW. A new tunnel was excavated parallel to the Isidra gallery and it serves as entrance for touristic visits. In addition, there are two natural cave entrances (Torca Ancha, Torca Juñosa and Braña Escondida), but their access is difficult. Preliminary studies (unpublished data) inside and outside the cave suggest that other entrances may exist, which influence the microclimate dynamics and cave environment. "El Soplao" Cave was opened as a show cave in 2005 (Gázquez et al., 2012). The cave was excavated in the Florida Formation, a shallow platform carbonate rocks of Early Cretaceous (Aptian) age.

This cave was discovered in 1908 by some workers of the mine. This cave-Mina is known worldwide for the many scientific findings, by speleothems and especially relevant for its eccentric formations. In recent times, it has been attributed to the generation and development of eccentric phenomena of capillarity, which could explain the genesis of multiple morphologies associated with these deposits. "El Soplao" presents numerous examples of these morphologies (Robledo Ardila and Duran-Valsero, 2009) and offers unparalleled view of many geological processes millions of years long; it has a visitable length of about 1800 m. Fig. 2 provides an inside view of one of the central galleries.

The cave and its surroundings are home to an exceptional heritage of industrial archeology mining as may be reflected in outer space with masts, kilns, laundry rooms, workshops, etc. Mining operations were aimed at extracting sphalerite and galena, two of the best ores for the production of zinc and lead, respectively.

Guided tours are organized from 10:00 a.m. to 21:00 p.m. in August with the maximum number of visitors and 10: 00 a.m. to 17: 00 p.m. in the months from November to March where the visits are fewer there are fewer visits (http://www.elsoplao.es/tarifas.php). The start of the visit takes place in a stretch by train from the outside the main entrance of the cave. Access is conditioned for a big part of the cave, including the use of wheelchairs. However, due to the unevenness of the cave, it has been carved by itself with rock steps and its visitable final section (from Bishop to Italians) is not ready for use. Guided caving-adventure that starts from the gallery of Italians into the cave tours is also available.

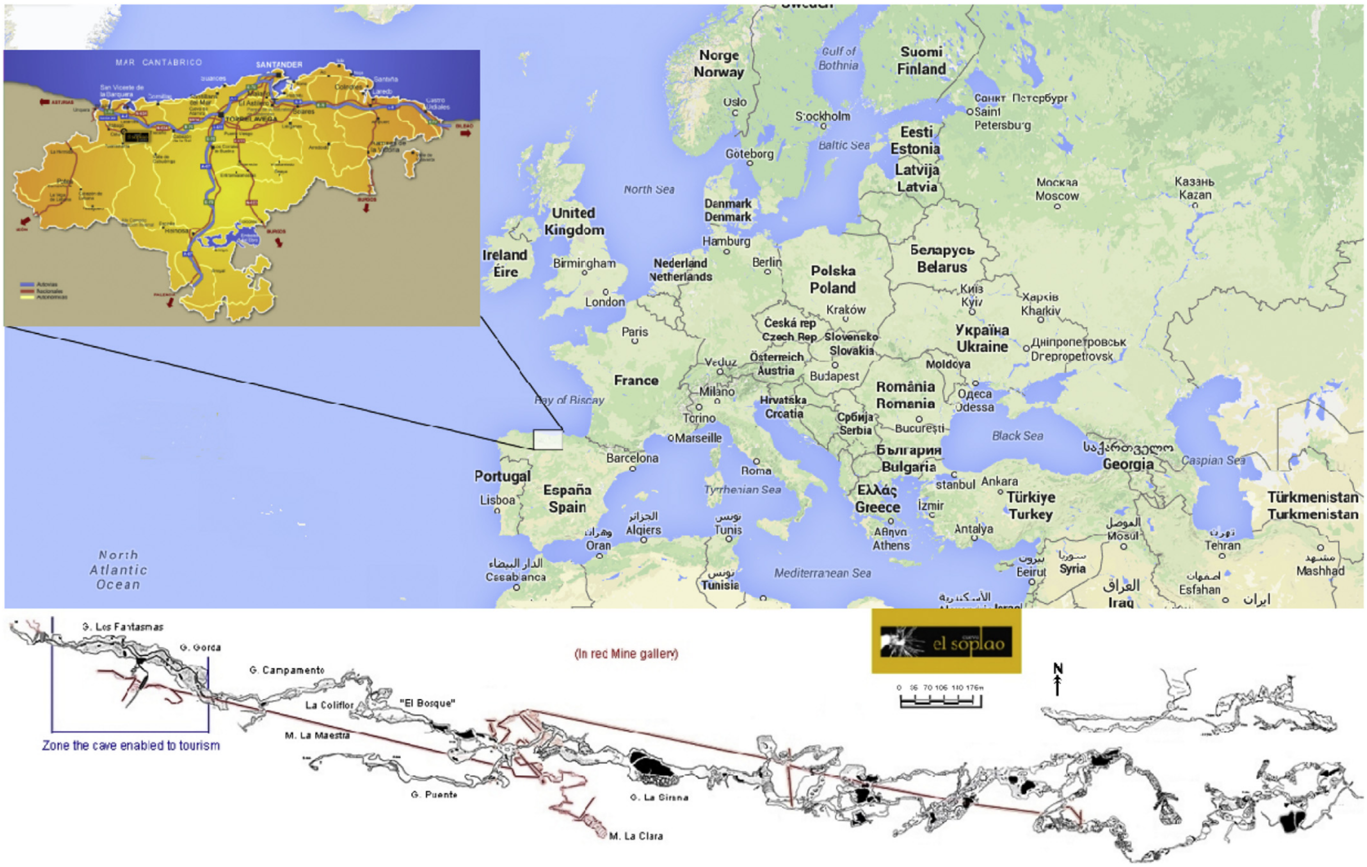


Fig. 1. Location of "El Soplao" Cave, and a plan view of a part of the cave.

Fig. 2. Internal view of ”El Soplao” Cave.

3. System and methods

The telemetry system of ”El Soplao” was designed and installed by the research group of Electronics Communications and Telemedicine “ECT” at the University of Almeria in collaboration with the group of Environmental Geology also of the University of Almeria, already jointly conducted with other technology projects such as the Gypsum Karst. This system has been in operation since 2006 (opening to the public). Currently, ECT engineers are in charge of technical monitoring system in collaboration with Tourism Nansa (responsible of the cave preservation). The data is also available for specialists in geology (group Environmental Geology at the University of Almeria) along with the direction of “El Soplao”, to analyze their progress and provide them with a tool to ensure optimal preservation of the cavity.

Although time is configurable, data is measured and recorded each minute. With this data, a database on a central computer is created. The data is accessible via the Internet in real time, both current and historical, through an interactive application that allows users to consult their evolution through graphical and numerical download in different formats for processing with other applications. It serves to assess the environmental impact of tourist visits and provide recommendations on the maximum number of visits and recovery periods between visits in order not to alter the microclimate developed within the galleries, not only of the visitable areas but the whole network of cavities Mine Cave. This cave has a wide acceptance in the number of visitors; as an example of data to be considered is the month of August 2015 where the number of visitors received reached its maximum with about 53,749 visitors this month.

To improve understanding of the natural meteorological conditions inside the cave, five stations monitoring sites were established in 2005 in parts of the cave that lie on the tourist path (Fig. 3, stations 1, 2, 3, V and C). The passage of tourists is also recorded at two stations of measures, at the start of the tourist route and another at the end of the visit in cave. They record the details of visitor numbers per year or per every visit. Exterior weather station was installed to assess the correlation with outdoor weather. Instrumentation of the stations 1, 2, 3 and V were installed about 1 m above the cave floor in airtight boxes and close to the cave wall. The E and S stations (Inflow and Outflow of visitors) were installed camouflaged about 20 cm above the cave floor in a narrowing driveway in the entry and exit to the tourist route in the cave.

The system has a dynamic and extensible architecture, which now has a total of 26 sensors measured in 8 stations distributed throughout the cavity, trying to cover the whole extent of the visitable area. The variables measured are: temperature (T), relative humidity (RH), CO2 concentration, air speed and direction within the cavity, caudal of drip, barometric pressure (BP) within the cavity, estimate of visitors flow to next areas of the measurement stations and hallways input and output. Also an outdoor weather station records are the same environmental parameters monitored within, allowing the comparison of interior and exterior climate. Fig. 3 shows a map of the visited area of the cavity and the distribution of the measuring stations with the sensors are shown in Table 1. A special cable communications and electricity runs through the all gallery and is hidden to the visitor. This cable connects all stations between themselves and with the control center. Artificial lighting with low impact on bioclimatic conditions the indoor has been installed in the visitable area of the cave.

A previous study of the recommended variables were done to obtain reliable information on the state of the cave, this study was done by the group of geology at the University of Almeria along with the technical team of the Cantabria Community responsible for its preservation. The variables are measured at each station according to the specific needs of the cave (previous study) and the local situation. Table 1 shows the complete repertoire of sensors connected in each measuring station.

The stations are located in areas that do not impede the passage of the visitors, but visitors can observe the readings of the parameters being measured at that time. Fig. 4 shows a view of the location of the stations in two galleries, you can see how the station is located at the edge of the paved area and is supported by a metal pole. Inside the pole are the cable of communication and powerline, which enter and leave the station. The cable is fully camouflaged within the structures of the cave or buried in mud.

A block diagram that contains the distribution of stations connecting sensors and functions of the central control station is

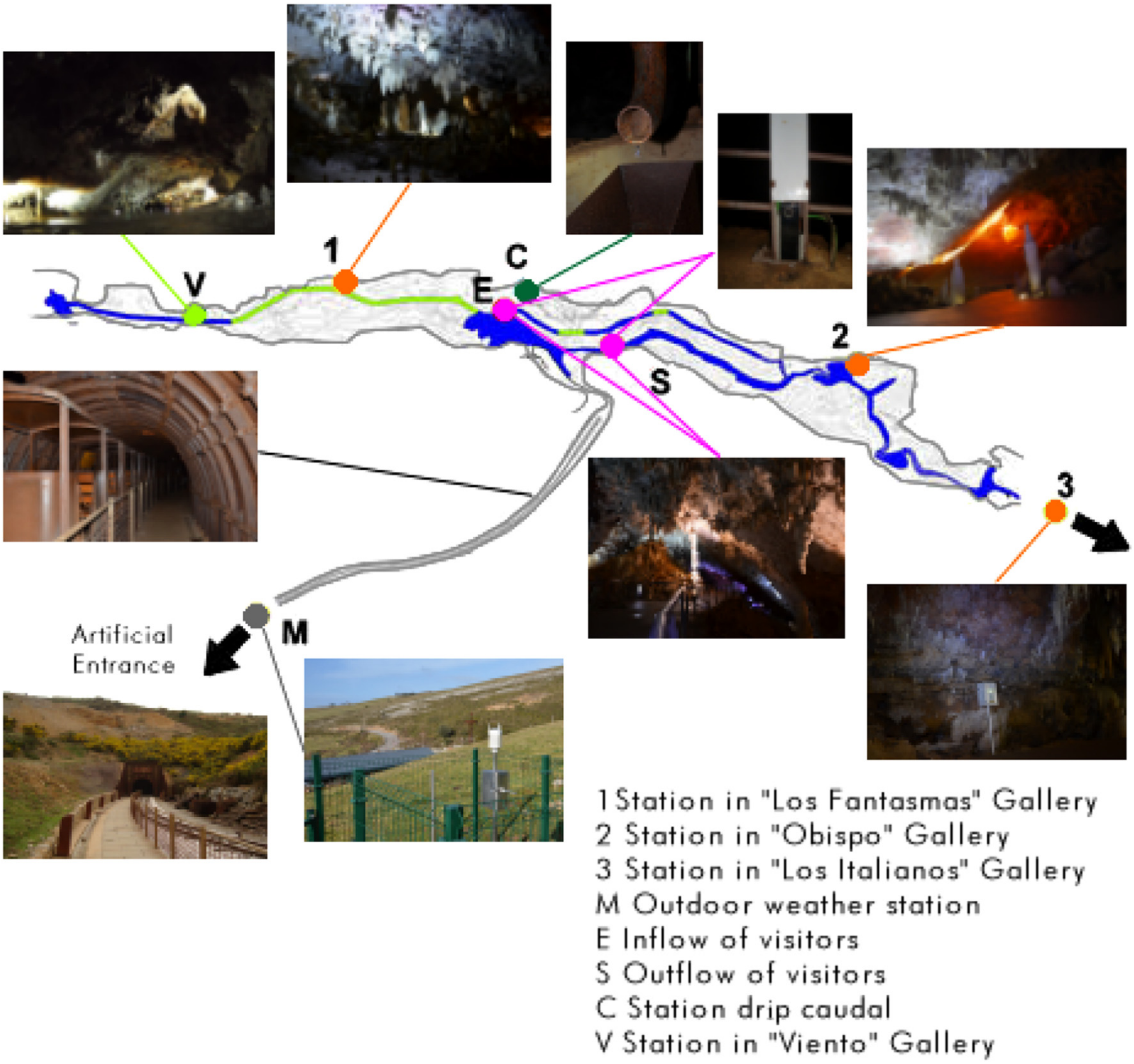


Fig. 3. Map of the area visited in the ”El Soplao” Cave.

Table 1
Distribution of the sensors measuring stations.

Gallery Name	CO2	Temp	Relative humidity (RH)	Presence	Wind speed	Wind direction	Rain drip	Barometric pressure (BP)	Account visitors
Fantasmas	●	●	●	●					
Obispo	●	●	●	●					
Italianos	●	●	●	●					
Outdoor weather (Meteo)	●	●	●		●	●	●	●	
Inflow of visitors									●
Outflow of visitors									●
Drip caudal							●		
Viento				●	●	●		●	

shown in Fig. 5. This diagram shows the distributed structure of the system where a set of sensors are connected as an independent station, governed by a microcontroller and real-time information from an internal clock that keeps track of time or power loose. All climatic parameters inside and outside the cave are measured and recorded continuously every minute with accuracy and Table 2 shows the detailed range for each sensor.

The number of daily visits are also recorded in detail by two distance sensors (photoelectric sensors) to which is applied an empirical formula to estimate the number of visitors by counting pulses produced by the passage of visitors The aim is to establish the influence of tourism on the cavity and establish a sustainable exploitation without the deterioration of the natural well.

3.1. *Central station*

The central station communicates with remote stations using a polling protocol consisting of the interrogation sequences of all stations. With a time stamp acquired, it transmits them as response packets of information with data from all sensors every season.

Fig. 4. a)Viento station (right of the image), b) Obispo station (Left of the image).

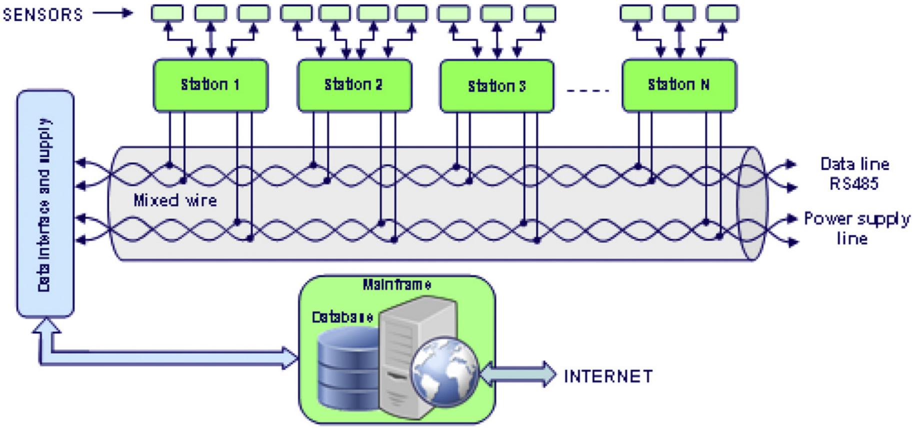


Fig. 5. Block diagram of the stations system.

Table 2
Basic features of the installed sensors.

Location	Sensor	Measurement range	Precision	Output resolution/comments
Inside	Drip	0.5–6 mm/min		0.5 mm
Outdoor	Rain intensity	0–200 mm/h	5%	0.1 mm/h
Inside	Temperature	−70 – +180 °C	±0.1 °C	Pt100
Outdoor	Temperature	−52 – +60 °C	±0.3 °C	
Inside	RH	0–100% RH	±2% [0–90% RH] ±3% [90–100% RH]	Function of temperature
Outdoor	RH	0–100% RH	±3% [0–90% RH] ±5% [90–100% RH]	0.1% RH
Inside/Outdoor	CO2	0 – 10,000 ppm CO2	<±20 ppm CO2 +2% of reading	0.03% FS[a]
Inside	BP	800 – 1060 hPa	±1 hPa [0 –+40 °C] ±1.5 hPa [−20–+45 °C]	0.1 hPa Operating temp.: −40 – +60 °C
Outdoor	BP	600–1100 hPA	±0.5 hPa [0–+30 °C] ±1 hPa [−52–+60 °C]	0.1 hPa
Inside	Wind speed	0–65 m/s	±3%	0.1 m/s
Outdoor	Wind speed	0–60 m/s	±3% [0–35 m/s] ±5% [36–60 m/s]	0.1 m/s
Inside	Wind direction	0–360°	±2°	1°
Outdoor	Wind direction	0–360°	±3°	1°
Inside	Presence	100° – 360°	4 m axis focal distance	Dual PIR + MW technologies
Inside	Visitor counter	0 – 3 m		

[a] Full Scale.

The central station performs a triple role:

a. Records the data on an interactive database for storage.
b. Provides real-time data via a Web server to user demand, both in graphic form curves and numerical format.
c. Provides consultation through Web server, any data or data group between any two dates recorded in the database

A physical Central Station is implemented on a computer. A server technology has been chosen by the Linux operating system, considering it as an option for stability. The database was implemented with MySQL standard, from which was developed an application of data mining and interactive graphical presentation on remote clients. This configuration provides high display quality with high reliability.

The completion of the interrogation or polling stations and the inclusion in the database of the measurements is obtained by a resident in service or daemon. The service is programmed in C language and provides high levels of security, by accessing the database to record the data from the sensors, each round of polling, preventing unwanted access to the database.

The response time varies between the instant reply if it is data of the day or a few seconds when dealing with large amounts of data (several days) on various dates.

Fig. 6 shows a view of the cabinet that houses the Central Control Station. At the top of the power module, communications unit and the console are shown in the middle shelf. And at the bottom, the computer is located. Two units or computers are used; one operating and one is reserved. This cabinet is located in a building next to the gallery where the offices and other units of the administration of the "El Soplao" Cave are located.

3.2. Remote stations

The remote stations are distributed inside the gallery except the outdoor weather station (meteo). The structure of these is based on an independent measurement system data. For better optimization of its operation, a specific purpose embedded system is developed. It serves for data acquisition, calibration and local communications.

Fig. 6. Closet of the central control station.

Fig. 7 shows a block diagram, which defines the structure of these stations, based on a microcontroller with embedded program. This system is basically responsible for obtaining the data from the sensors and communicating with the central station to deliver it. Specifically remote units perform other transparent tasks to the central station, such as data preprocessing, from where the application of the microcontroller filters, scales and properly formats the digitized data from the sensors. In this way, information is directly supplied to the central station from the remote units. In addition, as security and monitoring system, a timestamp at the time of the acquisition is inserted into the communication frame. It will allow you to index data according to the exact time it was measured at.

Fig. 8 shows a picture of remote data acquisition module developed at the University of Almeria, which also includes a switching power supply unit to supply all the internal tensions and some external for certain sensors, which operate at different voltages to 24 V (voltage supplied by the mixed communications cable).

There are several types of remote stations, depending on the number of sensors that are connected (Table 1). The stations 1 (Fantasmas), 2 (Obispo) and 3 (Los Italianos) has the same sensors: CO2, relative humidity, temperature and presence, Fig. 8 shows a view of this type of stations.

On the left side of the station of Fig. 9, the CO2 temperature and relative humidity sensors are seen up and down. The CO2 sensor is of infrared absorption type, widely used in these applications, the temperature sensor is Pt100, high precision and the relative humidity of capacitive technology. Inside, central zone, one can observe the data acquisition module. In the outside view of the right, the illuminated presence sensor is shown in red. The display with CO2 reading and below the keyboard is also seen. These stations record the basic parameters of the cavity to be measured in several places to study developments in the medium and long term effects of the visits in the different cavities.

Another type of stations is adapted to measure parameters that have little variation over the cavity, such as the atmospheric pressure and the moving air which simply measures the moving of Central air at any point when the cavity is roughly tube-shaped which allows to have the necessary information. The wind station measures air speed and direction, atmospheric pressure and the presence of bystanders. Fig. 9 shows an image of this station.

Another type of stations is adapted to measure parameters that have little variation over the cavity, such as the atmospheric pressure and the moving air which simply measures the moving of Central air at any point when the cavity is roughly tube-shaped which allows to have the necessary information. The wind station measures air speed and direction, atmospheric pressure and the presence of bystanders. Fig. 10 shows an image of this station.

At the top of Fig. 10, the ultrasonic measuring air speed and direction sensor can be seen. They consist of three triangle transducers that emit ultrasonic pulses and measure the time of arrival at the adjacent transducers. This sensor has a digital output to determine air speed and direction without mechanical elements. This system benefits from an acceptable accuracy in cavities that can appreciate 1 cm/s. The atmospheric pressure sensor, takes the air located on the left side of the box with a transient buffer fluid to prevent air movements from affecting the measure.

Another external remote station is meteorology (weather station): It is aimed for measuring the external environmental parameters that help correlate what happens inside the cavity with what happens on the outside. For example, relying on the rainfall outside, when and how leaks occur within the cavity.

Fig. 11 shows an image of the outside weather station. At the top appears a ventilated box that houses the temperature sensors, humidity and atmospheric pressure. The top is crowned with a

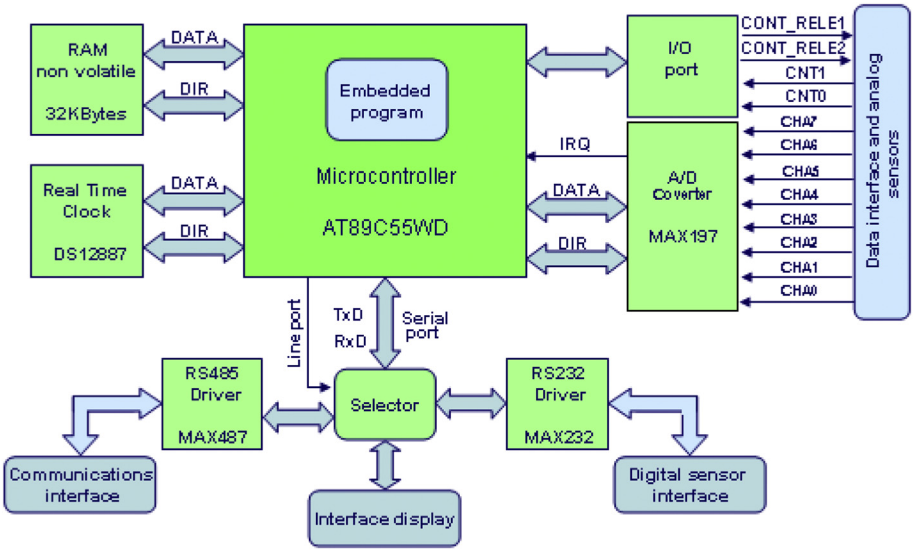


Fig. 7. Block diagram of the acquisition remote system.

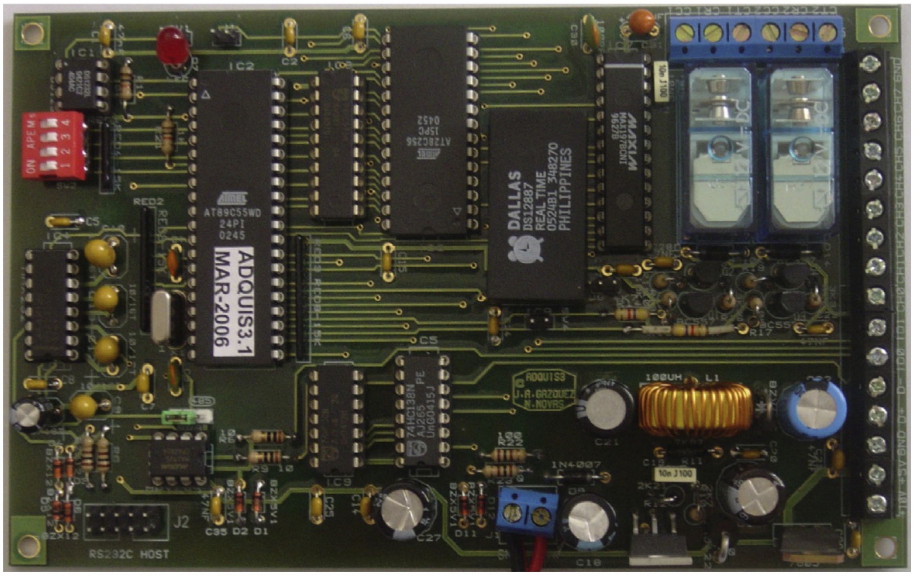


Fig. 8. View of the remote microcontroller module.

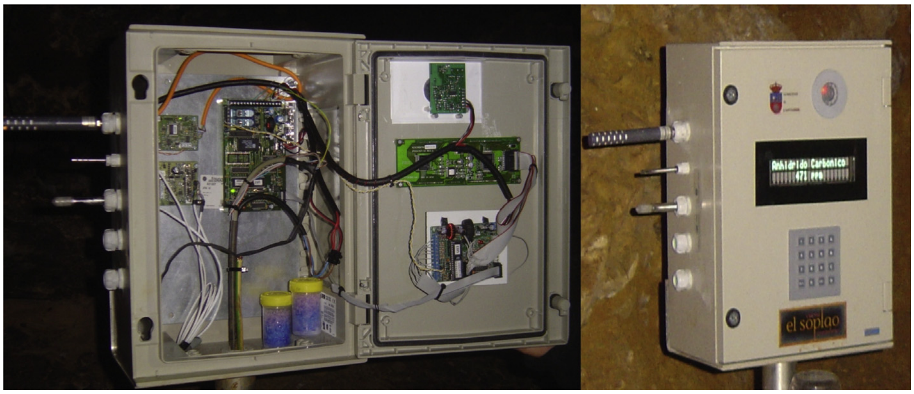


Fig. 9. Interior and exterior view of a remote station CO2, RH, Temp and presence.

Fig. 10. Inside and outside view of the remote Viento station.

piezoelectric plate counting raindrops and delta distribution sensor that measures the speed and direction of air. These sensors are a compact station with a digital output. On the right side, there is the CO2 sensor with analog output.

All the sensors, the compact station and CO2 sensor are integrated in the module of acquiring meteorological station for transmission to the central control station.

Because it is the only outside station that must provide sufficient information to correlate external influence of all parameters measured along inside the cave, this station contains the highest number of sensors. There are other less complex remote stations, such as input and output beacons, which allow estimating the number of accessing people by means of infrared beams in real time. This data is correlated with the alteration of internal parameters such as CO2. Another less complex station is the inner drip counter. Through a funnel placed in the drip greater spoon, there exists a counter that measures the flow of water seeping.

Fig. 11. View of the exterior weather station (meteorology).

3.3. Environmental data collection

The data server allows obtaining environmental data measured by the remote stations ubiquitously through Internet. Fig. 12 shows an image of the application portal, which appears once entered into the system.

Using the map view of the cave with the situation of the seasons and the menus on the left, you can select between current practice stations or variables, 1st and 2nd tab; or measures of previous days, database, graphical output option or numeric option, option management Database. Moreover, the portal allows other specific functions of monitoring and maintaining the system, allowing performance of actions at a distance, and avoiding unnecessary travel of personnel service.

Fig. 13 shows the screen obtained by varying the current query. In this case, temperature may be obtained as an independent graphical or by combining different curves on the same graph. Specifically, inner temperatures moving in a very small range of variation can be shown on the same graph and therefore the curve is shown in greater noise. In addition, outdoor temperature is shown in a separated graph apart. Because of its major variations, it cannot be displayed on the same scale of the inner temperatures. Italian gallery is the deepest and most visited only as caving adventure, it is the one with the lowest temperature. At any time, all graphs are influenced by movements of air at any temperature.

A numeric format consultation is also possible. Table 3 shows a fragment of the numerical data of weather station measured minute by minute.

Data from this station (Table 3) numerically available in ASCII format may be processed by other applications such as Matlab to perform time series studies or other that are more specific directly on the downloaded files.

Environment Management System
Cave "El Soplao"

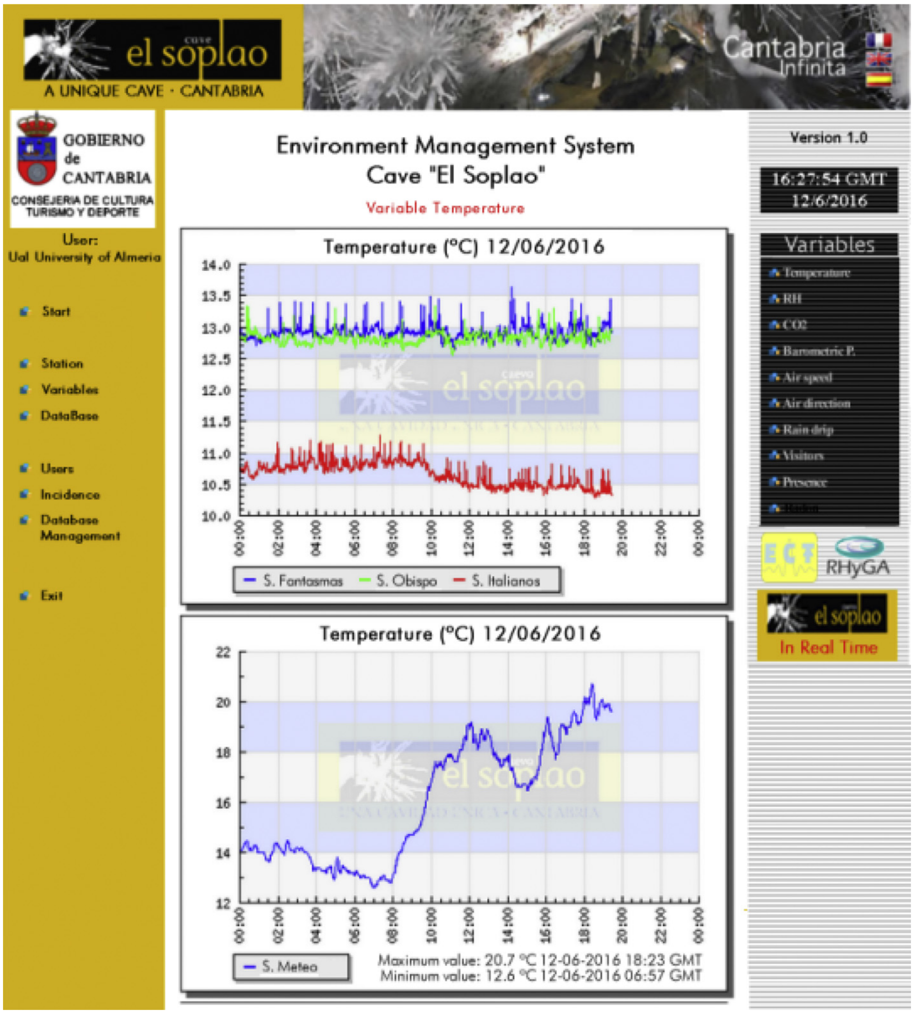
Version 1.0

16:55:46 GMT
11/6/2016

Clic on the station to see data in real time

© 2007 Ministry of Culture, Tourism and Sport of Cantabria | All rights reserved
System developed by the Research Groups 'Electronics, Communications and Telemedicine' TIC019 and 'Water Resources and Environmental Geology' RNM189, the University of Almeria.

Fig. 12. Interactive view of the Web portal application data query.



Environment Management System
Cave "El Soplao"
Variable Temperature

Version 1.0

16:27:54 GMT
12/6/2016

Maximum value: 20.7 °C 12-06-2016 18:23 GMT
Minimum value: 12.6 °C 12-06-2016 06:57 GMT

Fig. 13. Evolution of one daily temperature.

Table 3
Data of the weather station in numerical format.

Date	Hour	Rain (mm/h)	Relative humidity (%)	Temperature (°C)	Barometric pressure (mbar)	Wind speed (m/s)	Wind direction (N°E)	CO2 (ppm)
04-06-2016	00:01:00	0	91.5	13.4	950	1.9	335	331
04-06-2016	00:02:00	0	91.5	13.4	950	1.1	299	331
04-06-2016	00:03:00	0	91.5	13.5	950	1.7	337	334
04-06-2016	00:04:00	0	91.5	13.4	950	1.5	359	360
04-06-2016	00:05:00	0	91.5	13.4	950	1.2	358	348
04-06-2016	00:06:00	0	91.4	13.4	950	1.1	357	360

Finally, a downloaded graphic is shown in Fig. 14. It shows the evolution of another parameter (CO2) in a day for several hours visits. In the graph you can see the correlation between visits and increased CO2.

4. Results and discussion

With the application shown in the previous section, the evolution of microclimatic parameters of the Cave Mina has been registered based on a previous study of the recommended variables that was done to obtain reliable information on the state of the cave. Figs. 15–17 show the evolution of the monthly average of the past five years and year 2008 of the 3 principal parameters (Temperature, relative humidity, CO2) that define the microclimate modification existing with the number of visitants.

2008 has been considered as the base year to make a comparison of the data recorded in the early opening of the cave with recent years. Temperature is shown (Fig. 15), relative humidity (Fig. 16) and CO2 (Fig. 17). Visits tickets accounted for by the company were depicted as reference data to see the influence of visits to the maintenance of microclimatic parameters inside the cave-mine.

The results show the relationship between the visits and the monitored parameters inside and outside the cave. The results show that the influence of visitors has marked a seasonal character, being the summer months (July, August and September) the busiest with a contribution between 50% and 60% of the annual total. And the winter months have fewer visits with an annual contribution of 8–13%.

The results show that the influence of the visits on the cave holds a seasonal character that reaches its peak during summer months with a percentage going up till 50–60%.

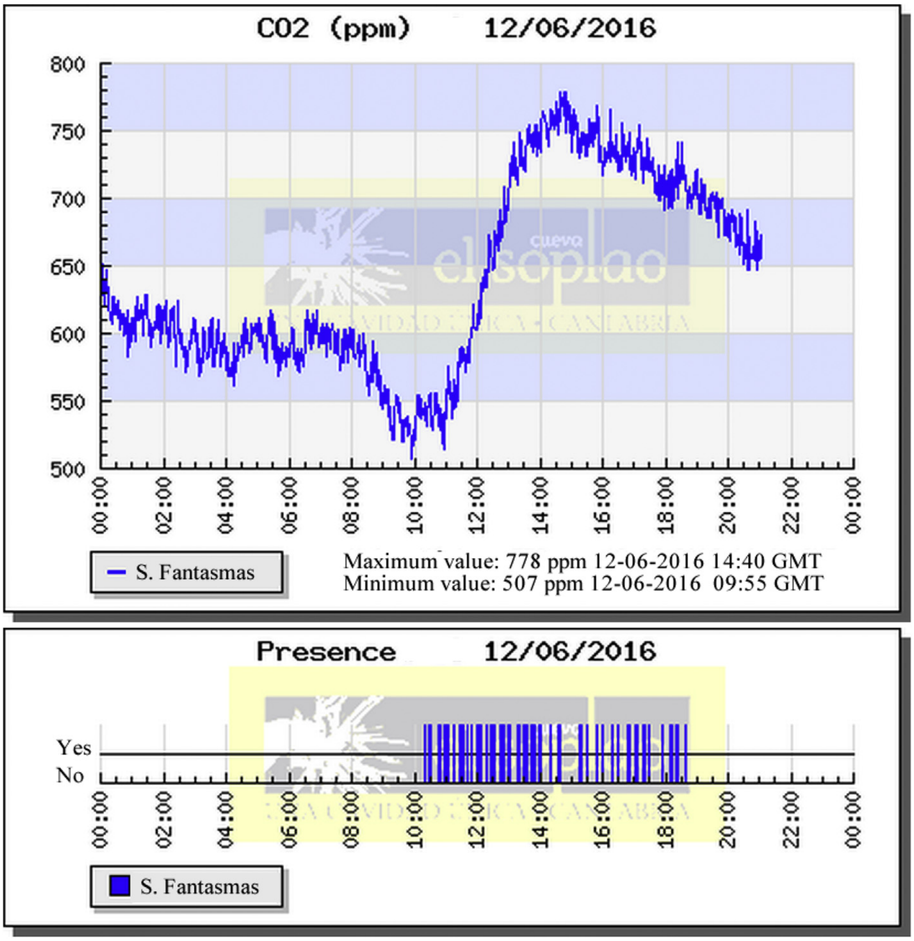


Fig. 14. Compared evolution of CO2 during one day with visits.

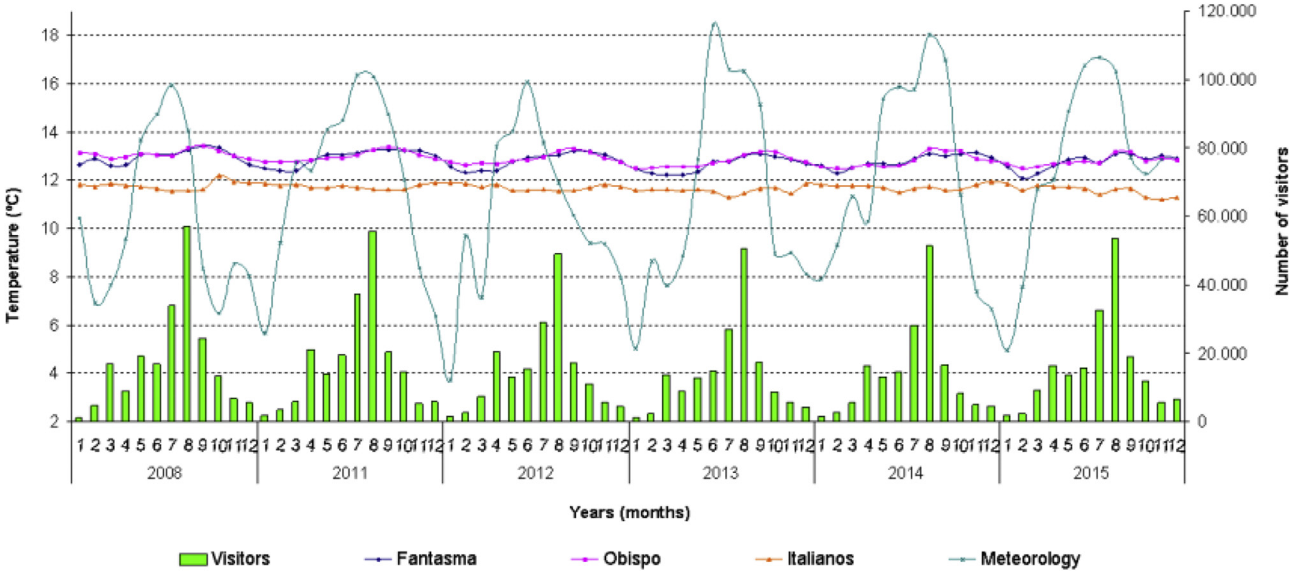


Fig. 15. Graphic of the temperature evolution and the number of visits in the years 2008 and 2011–2015.

The number of data collected up to now is high and correspond to 6 years of operation of the cavity. The study of the monthly averages of data from all stations, allows a number of conclusions in relation to each parameter:

- The temperature is the parameter inside the cavity that presents the less variation, with a seasonal quasi-periodic variation of ± 0.5 °C within the two stations of shallower cavity (Bishop and Ghosts), (Fig. 15), whereas the deepest station (Italian) maintains a more uniform temperature over time ± 0.2 °C, without accusing a clear correlation with other parameters. If the quasi-periodic change appears clearly correlated with the number of visitors and the outside temperature of the cavity, this factor cannot be associated directly to a single cause. The peak number of visits and the external temperature coincide annually during August while the maximum temperature of the cave with the month of September. Hence, it is true to attribute this change to the fact that there is a semi-ventilated cavity in the cave having a thermal inertia affecting the external temperature with a one month of delay. Because the number of visitors has very close peaks with peak external temperatures during the months of July and August, it is difficult to associate one with another because both happen in the same month. In order to establish an accurate judgment on the cause of the periodicity of indoor temperature, it would be necessary to close the passage of people to the cavity for a year. This does not seem necessary because a trend of increasing temperature outside seasonality cannot be established currently.
- Regarding the relative humidity, its small variation has no correlation with the outside relative humidity or with the number of visitors accessing the cavity. The relative humidity seems only to depend on the depth of the station within the cave environment with 89% on the first level and 94% at the second level (Fig. 16).
- If the CO2 concentration has a clear correlation with the number of visitors (Fig. 17), it is returned to the fact that these are a major source of CO2. Monthly averages are maintained between 450 and 750 ppm in the first level stations (Bishop and Ghosts) and between 500 and 1000 ppm in the second level stations (Italian). In some years the peak of CO2 presents a slight delay on others, probably due to the accumulation and movement into the sump of a gas heavier than air gas. CO2 concentrations are maintained as such and at much higher values in the exterior air due to the influence of the visits. When you have data for a few more years, it would be possible to determine long-term cumulative effects.

As a final conclusion we can say that the parameters, being measured continuously, are of extraordinarily interesting and valuable to determine the effects of visits inside the cavity as it is possible to study the evolution of the most significant data based the influence of visitors. Today, it cannot be said that there is a clear cumulative incidence in the stability of the cavity due to the visits.

In the cave of “El Soplao” in Cantabria, a new system of telemetry and control of environmental parameters has been installed which allows real-time access to all the variables from any location. This system is a great advantage and innovation based on the classical systems of dataloggers. In the study of cavities for both scientific purposes and tourism control, cavities have employed widely registration units called loggers, which enable the measurement and recording of measured values until later downloading in-situ and data analysis. These unloading of data and analysis at a later time are made with a certain frequency depending on the battery life of the logger, which can be more than one month. This method allows learning what happens to deferred time; it is also necessary to go regularly download data. These systems have the drawback that if for any reason no discharge takes place at maximum deadline the measured data may be lost therefore depleting battery or exceeding the storage capacity. In some projects like Lechuguilla Cave (Mexico) (Land and Burger, 2008), changes in water levels in aquifers and indoor pools are measured to study the evolution water in the presence of other wildlife projects studied as bats with ultrasound recorders that record in the caves of Cheddar (South West England) (Park et al., 1999). Similar systems have been used to study the impact of visitors to the caves, one example is the study of (Sanderson and Bourne, 2002) where temperatures were studied over a period of two years and the relative humidity in four different caves National Park Naracoorte Caves in Australia, two of the caves near a visitable area and two deep and far from visitable areas. Another example is the study of CO2 in the numerous cavities that houses the Rock of Gibraltar (Mattey, 2012), which are recorded monthly over 250 m

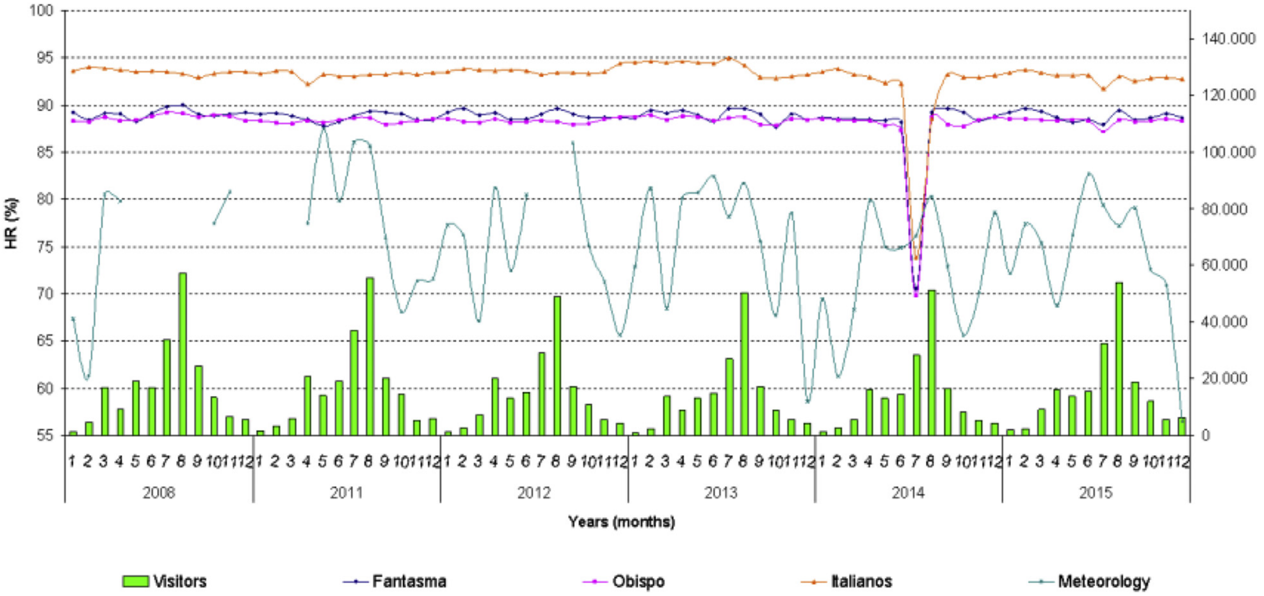


Fig. 16. Graphic of the relative humidity evolution and the number of visits in the years 2008 and 2011–2015.

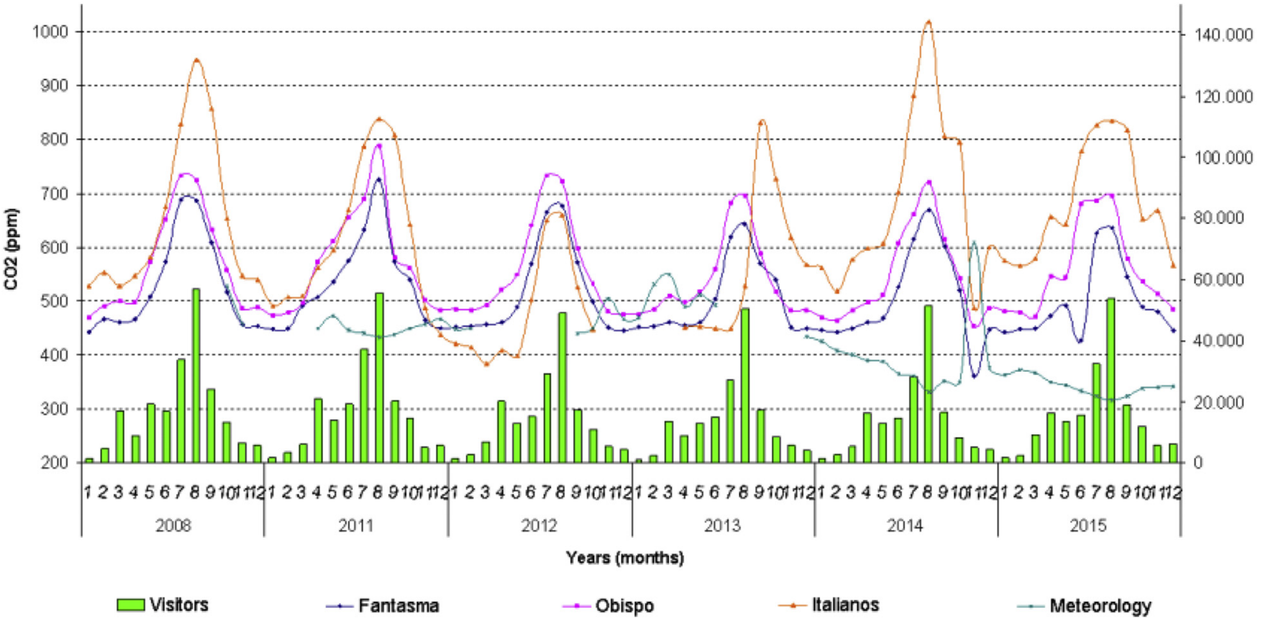


Fig. 17. Graphic of the CO2 evolution and the number of visits in the years 2008 and 2011–2015.

cave in a datalogger variables such as temperature, humidity and leakage.

In Spanish tourist cavities such as the Cueva de Nerja (Benavente et al., 2007), the CO2 evolution is studied. In 2008, another work is published by dataloggers of “Agua Cave” (Granada) which contains an interesting balance hydride study conducted by external and internal gallery weather stations (Fernandez-Cortes et al., 2006). In all these described studies, it is known what happens once the data are collected and analyzed, which allows the detection and interpretation of what happens in the cavities for several months.

In the market, there is a variety of commercial data acquisition devices. Specific purpose systems, as developed, allow the optimization of remote stations and increase the degree of autonomy which results in a more reliable and more easily reconfigurable system. That is, there is an open system that allows absolute control over the whole control system and the communications are configured as needed. The custom system is only closed to permit configuration of inputs and outputs.

Another available functionality in the acquisition module, and that could not exist in standard commercial systems. It gives the possibility of connecting sensors with digital output through the digital interface, and is selectable by multiplexing sensors in time. The information of digital sensors is incorporated in analog converted data and therefore climbing, marked and treated the same way as analog sensors, homogenizing all sensory information.

There is a need to adopt a vision for long-term management strategies suitable for the environment. Sustainability is considered as a development approach but is costly and therefore tends to

Table 4
Average of daily visits per month and year.

Month	2008	2011	2012	2013	2014	2015
January	39	55	45	33	47	58
February	163	120	94	80	96	82
March	542	192	229	438	174	296
April	299	693	676	295	540	539
May	615	446	419	415	417	442
June	564	644	510	496	486	524
July	1.090	1.193	936	874	909	1.047
August	1.842	1.792	1.580	1.627	1.654	1.734
September	808	676	573	576	554	625
October	428	471	351	282	264	387
November	219	171	181	185	168	185
December	181	185	139	133	141	201
Total visits per year	208.127	203.202	175.600	166.653	166.890	187.569

decrease its priority over economic performance. There are studies for the sustainable use of touristic caves as Predjama (Šebela and Turk, 2014), where the increase of visitors in this cave is monitored since 2009. Its findings expose the need to determine a plan for a future regulation to increase planning studies visits, as current visits (6000 per year) do not imply anthropogenic influence on the natural microclimate of the cave.

In former mining areas, the economy can be stimulated and the heritage tourism can be increased. Because the heritage resources possibilities cannot be measured, one of the major problems to surpass resides in the difficulty of measuring the availability of this economic impact (Pérez-álvarez et al., 2016). There is a preliminary study for calculating the maximum visits made by the group of geology involved in the preservation of the cave. In this study the data of August 2013 was taken into account in the Gallery of Ghosts and Bishop (Guirado et al., 2015). The researchers conclude that the maximum daily number of sight to avoid irreversible deterioration in microsystems of the cave is about 1900 visits daily. Hence in their conclusion, they propose to do a deeper study taking into consideration the available data from outside the cave (Meterology station) with different periods and visits in a future work. The box office data in Table 4 shows that the number of visitors is not exceeded even in the month of peak traffic; these data are not taken into consideration, nor the guidelines that accompany each group or maintenance staff. The capacity of the cave visits should be flexible, conditioned by the environmental monitoring. Years should be minimized years and the benefits of all parties involved should be maximized. The fact that the regeneration of these special environments is limited or nonexistent in some cases should never be forgotten.

As shown Fig. 17, when the graphic of the CO_2 evolution is in the top for one month, august, then the number of visits for next two months is decreased by maintenance staff; after that, in next months the parameter of CO_2 is taken range values (400–600 ppm). This is an example of how monitoring system can help to maintain the sustainability of the cave.

5. Conclusions

With the aim of determining the state of the natural asset being used for tourism and for development of a sustainable preservation program, the use of telemetry proposes a new method of study that enables a new way to feel and understand the environment. All parameters are measured in terms of determining the potential impacts of their exploitation. The results of the eighth-years of monitoring will provide the bases of the application of guidelines within the sustainable preservation plan. Continuous monitoring facilitates developing a flexible plan for regulating potential visitors.

Cave morphology and the positions of the passages and entrances are important factors in understanding the cave microclimate, where influences of external temperature can penetrate deep inside the cave. There are distinct winter and summer air circulation regimes into, through and out of the cave.

Currently, the influence of tourist visits on the cave's microclimate appears significant because there is an over-riding influence from surface climate conditions in the parts of the cave used for tourism. It is favorable that regular systematic monitoring of parameters occurs. Any large increase of tourist numbers visiting the cave, together with the impact of electrical installations can change the underground environmental conditions. From the engineering point of view, the results show the effectiveness of this type of system where intelligent control telemetry is established. It allows accessing data in real time and from anywhere. It also facilitates the system maintenance which results in a better and access and more direct control of the operation of all the installed elements. On the contrary, this type of projects represents a major economic investment in the facility; a study and custom design are essential, which necessarily requires more runtime than other systems.

From the point of view of commercial exploitation, it could be argued that the cost of a long-term operation can be more economical because it reduces travel costs and allows immediate action in case of altering any parameters that need attention, avoiding greater evils and promoting faster recovery of the environment. To act immediately in recovering the cavity is very important for the commercial exploitation of tourism cavities, where the number of visitors and continuity can modify the microclimate of the cave and therefore affect the own unique formations of these conditions. Results show a high correlation between CO_2 and the number of visitors. An exhaustive control of the parameters inside the cave is necessary to keep track closely of their variability and observe the alterations in the geological structures. With these systems, telemetry is allowed to manage the number and duration of visits without interfering in changing the very conditions of the cavity. This system can serve as a basis for maintaining a sustainable and profitable exploitation of such biologically active cave in other touristic natural good caves.

Tourism can increase incomes and stimulate the economy in former mining areas. The measurement of the geologic impact is one of the main problems to confront; monitoring can help us relate the economic-geologic impact permitting a sustainable regulation.

Acknowledgment

We thank the Ministry of Tourism of Cantabria for trusting researchers at the University of Almería and realizing this project. As well the Nansa Company Tourism located at "El Soplao" that continues year after year to count on the University of Almería to conserve this measurement system. Finally, we thank the Government of Andalusia, that through aid groups TIC019 Research and RNM189 allow more measurements at the University of Almeria to investigate the improvement of measurement systems and the interpretation of environmental reports.

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