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Analysis of the European tourist mines and caves to design a monitoring system

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Abstract
A database of tourist mines and caves has been created to investigate the requirements of an integrated monitoring system with the aim of ensuring the safety of visitors and preserving the environment of the activities. It contains the main features of each site, in particular the physical, geological and technical information. The results unfold the main characteristics of these sites and give an insight of the parameters to be monitored: number of visitors, temperature, noise, gas concentrations, ground movements, among other factors. All these features are crucial for the safety of tourists and guides, as well as for the preservation of biodiversity and geodiversity. This information will be used to create a system capable of controlling the entire underground activity, such as the one tested in the two case studies.

Keywords: safety; geoheritage; tourism; monitoring; European Union.

Análisis de las cuevas y minas turísticas de Europa para diseñar un sistema de monitorización

Resumen
Se ha creado una base de datos de cuevas y minas turísticas para investigar los requerimientos necesarios para implementar un sistema integrado de monitorización capaz de mantener las condiciones de seguridad de los visitantes y el ambiente adecuado de la actividad. Dicho sistema controla las principales características físicas, geológicas y de información del sitio. Los resultados detallan las principales condiciones de las cuevas y minas turísticas, mostrando los parámetros importantes a controlar: Número de visitantes, temperatura, ruido, concentraciones de gas y movimientos del terreno, entre otros. Todos estos parámetros son fundamentales para mantener la seguridad de los turistas y guías, así como para preservar la biodiversidad y formaciones geológicas particulares de cada sitio. La información incluida en este estudio se usará para obtener un producto similar al mostrado en los casos de estudio.

Palabras clave: seguridad; patrimonio geológico; turismo; monitorización Unión Europea.

1. Introduction

The exploration of natural caves and tourist mines has become increasingly popular in recent years. Around two million people visit caves at national parks in the United States each year [1] and a similar number do so in the European Union (EU). For instance, the Postojna Cave in Slovenia had nearly 500,000 visitors in 2010 [2], while caves from the Dordogne region of western France receive thousands of visitors every year, and more than 20,000 people venture annually through Ireland's Marble Arch Caves Global Geopark or approximately 800,000 tourists visit the Drach Caves in Mallorca, Spain [3].

Besides, the use of mines as a sightseeing place is increasing, especially after mine closure. This activity provides an economic alternative when the natural resource is not economically worthwhile [4]. Tourist mines can constitute a place where visitors can learn about mining and how the society was in mining settlements [4]. Mines are used as tourist places around the world, for example, Coal

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mines from Wales [5], the Wieliczka Salt mine in Poland [6], La Union from Spain [7] or the Gambatesa Mine in Italy [8].

Visitors are usually unaware of the risks in underground environments and may behave unpredictably in critical situations [9]. Moreover, many tourist underground places are not equipped with an adequate monitoring system to guarantee visitor's safety, and several authors have reported accidents occurring in underground tourist sites [10]. Although control measures have been widely implemented to mitigate these hazards, there is still a long way to go in improving safety levels.

In addition, atmospheric parameters are very important for the conservation of speleothems and microorganisms in caves and are usually influenced by the number of visitors [7,11-13]. Body heat and lights contribute to increasing the temperature and changing the degree of humidity and evaporation rate [13]. While the air exhaled by visitors can substantially increase CO_2 levels [14], CO_2 levels above 5000 ppm (parts per million) can be dangerous to humans, whereas more than 2400 ppm can deteriorate cave formations or speleothems [15]. Radon is another gas of interest formed by natural radioactivity [16-18]. The presence of radon in confined spaces, such as caves and mines, may be harmful to the health of visitors and guides [19-21]. The control of radon is also important because it is a tracer to predict earthquakes, volcanic eruptions and air movements [22]. Therefore, it should be monitored in tourist caves to obtain correct calculations of the annual effective dose per visitor and to guide and preserve the activities [16]. Currently, European law requires regular controls in tourist mines and caves [21].

Tourist mines and caves are an important part of our heritage as a society. Mines have provided essential raw materials for industrial processes. Nowadays, some abandoned mines have been converted into tourist attractions to educate the public about the geoheritage of the area. Unfortunately, most of the research has focused on archaeological aspects and relics. As a result, castles, churches and other sites associated with important historical events have received great attention, while mining and industry have been among the least-known aspects of heritage [23]. Nevertheless, in recent decades, various authors have begun to study the geoheritage of these places [23,24].

The present study aims to contribute to the development of a technical system designed to ensure safety in underground tourist sites and preserve its optimal environmental conditions. The system consists of specialized wireless ZigBee-based with static and mobile nodes for detecting various parameters and sending corresponding signals to a central unit to process the inputs; for instance, temperature, noise, gases, ventilation, environmental conditions or slow movements (falls, movements in floors and ceilings of galleries, etc.). The system also includes the real-time positioning of visitors. There are several products available in the market that performs some of these functions [25], but they are too expensive for most tourist activities or only consider limited aspects such as monitoring the location of visitors [26,27]. For this reason, a novel product specifically tailored, easy-to-use with low-maintenance was proposed. The developed product will be tested prior to commercialization in several tourist caves and mines in the EU. A database of the safety characteristics from different tourist caves and mines has been gathered as a first step to determine the situation in such activities.

1.1. Safety legislation in the European Union

The regulatory framework applicable to tourist mines and caves is crucial in the development of a technical system designed to ensure safety in underground tourist sites. These regulations cover the planning (permits and licenses for the activity), safety, electrical and electronic devices, as well as the threshold limit values for gases. Furthermore, underground tourist sites may be affected by other laws, such as those concerning the natural environment (protection of ecosystems, animals and vegetation), water, town planning, mountains, geological heritage, etc. The regulatory framework from Germany, Austria, Spain, France, the United Kingdom, Ireland, Italy and Portugal has been analyzed, choosing these countries because they include 70% of all the tourist mines and caves in the EU. Other countries with a long mining tradition were also analyzed.

The mining legislation has not yet been harmonized within the EU. However, there is a specific law concerning health and safety: The European Framework Directive on Health and Safety at Work (Directive 89/391/EEC of 12 June 1989; OJ L 183, 29.6.1989), which has been transposed into the national law of the EU member states. The purpose of this Directive is to improve the safety and health of workers. It includes general principles concerning prevention of occupational hazard, safety and health protection, elimination of risk factors, accident information, consultation and participation of workers in accordance with the national laws, training programs for workers and their representatives and general guidelines for the application of these principles.

On the other hand, Directive 92/104/EEC of 3 December 1992 sets out the common EU regulatory framework for safety in the mining sector, including minimum requirements to improve the protection of workers' health and safety in surface and underground mining (12th individual Directive adopted under paragraph 1 of Article 16 of Directive 89/391/EEC). These basic rules have been transposed into national law by each EU member country, and some countries have even introduced more stringent and more specific regulations.

In most cases, mine safety legislation is the only specific reference for underground tourist sites in the EU. However, regulations have been enacted and guidance notes have been compiled for tourist mines and caves in other countries, such as Australia, where the Queensland Department of Mines and Energy published the Guidance Note QGN 08: Safety at Tourist Mines: Mining and Quarrying Safety and Health Act 1999, or in the United States with the Regulations of the Mine Safety and Training Program for Tourist Mines on 30 November 2002 (2 C.C.R. 407-6).

The presence and concentration of pollutants should be controlled at these sites, with each gas having its specific threshold limit value (TLV). However, there is no harmonized legislation for TLVs. Some countries have established national regulations, while countries with no national regulations generally adopt the values indicated by the American Conference of Industrial Hygienists (ACGIH) or by the EU Directives. For example, EU Directive 96/62/EC states that EU members must adopt measures to ensure that carbon monoxide (CO) concentrations in the air do not exceed 10 mg/m^3 (average of 8 hours), and EU Directive 96/29/EURATOM states that radon levels must be monitored in natural caves and mines. The ACGIH has also established a maximum concentration of 5000 ppm of carbon dioxide (CO_2) for 8 hours. The International Commission on Radiological Protection (ICRP) (1994) recommends the annual effective dose of radon, implemented by national regulations such as the Spanish Royal Decree 783/2001.

2. Methodology

A database of underground activities has been done by means of the ArcGIS software, with 549 caves and 324 mines, containing their physical and geological characteristics (Fig. 1). Specialized sources were consulted for this purpose, and a survey was needed to obtain more specific information and design an efficient monitoring system.

The open circles stand for caves that did not respond to the survey, while the ones that answered the survey are represented with filled circles. On the other hand, the crosses are mines that did not respond to the survey and filled circles with a white cross of mines with an answer.

The questionnaire was developed in nine languages: English, Spanish, Catalan, French, Polish, Italian, Estonian, Portuguese and German. It was designed to obtain short responses with three main sections:

1. General information of the activity.
2. Seventeen items relating to physical characteristics, technical aspects, environment, safety, and tourist cave regulations in the country.
3. Nine questions to evaluate the utility of the research project.

Some questions were open-ended, while others had a multiple-choice or using a five-point Likert scale. The Cronbach's alpha coefficient was applied to validate the questionnaire [28,29], obtaining a value of $\alpha = 0.827$, indicating its internal consistency and reliability. The initial mailing to 873 facilities (549 caves and 324 mines) was answered by 51 caves and 38 mines, which represents 10.2% of the total, with a maximum sampling error of 12%.

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2.1. Undersafe system

Using the information gathered, a system to control tourist mines and caves was created. It consists of a basic unit controlled by a low-power ARM processor. The equipment includes:

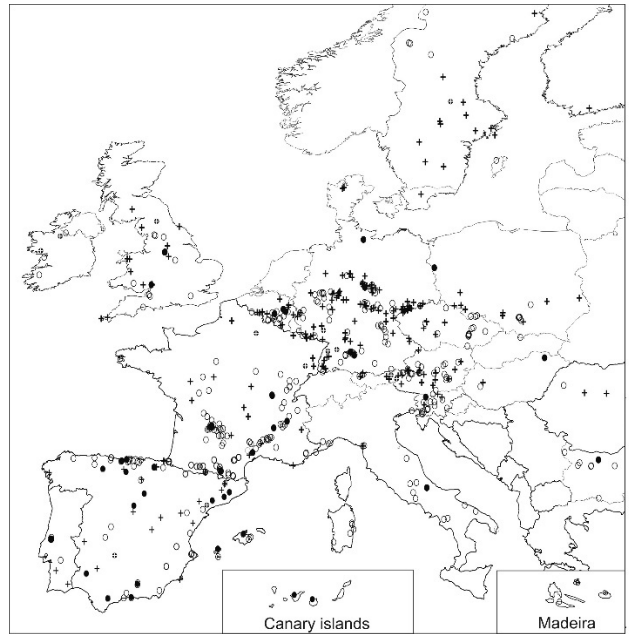

Figure 1. Location of the mines and show caves included in the database.
Source: Authors.

- Long distance RFID reader module
- ZigBee communication module
- Battery backup module
- Emergency lighting
- Internal intercom speaker

Communication took place via an Ethernet cable of 1 Gb capacity. It can be done via Wi-Fi module in situations where it is not possible, which is an integral part of the device. The system is able to:

- Track personnel and visitors
- Act as a communication system
- Soil sound detection and underground vibration
- Real-time monitoring of the underground environment: CO, CO2, O2, temperature and humidity.

All this information can be monitored by mobile phone or computer. Fig. 2 displays the system exposed above.

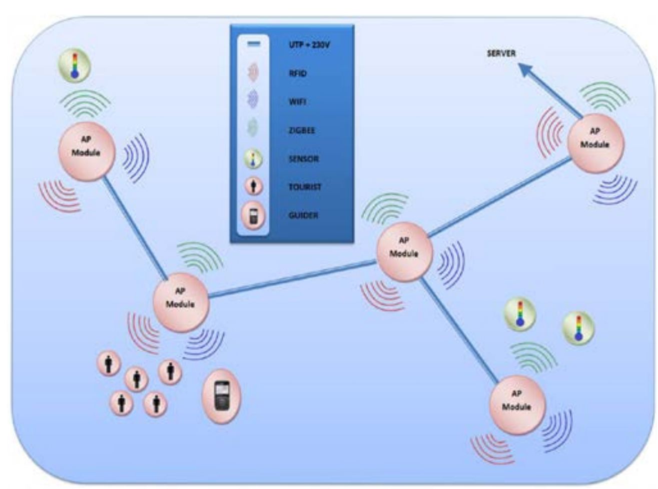

Figure 2. Undersafe system created.
Source: Authors.

Table 1.
Number of surveyed mines and caves and answers per country.

Country	Mines or caves	Answers	Percentage of answers (%)
Austria	72	3	4.2
Belgium	25	4	16.0
Bulgaria	19	2	10.5
Croatia	11	3	27.3
Czech Republic	23	0	0.0
Denmark	3	0	0.0
Estonia	1	0	0.0
Finland	5	0	0.0
France	180	15	8.3
Germany	213	14	6.6
Hungary	5	1	20.0
Ireland	5	3	60.0
Italy	44	2	4.5
Luxembourg	1	0	0.0
Malta	1	0	0.0
Holland	2	0	0.0
Poland	33	2	6.1
Portugal	18	1	5.6
Rumania	18	0	0.0
Slovenia	22	2	9.1
Spain	103	32	31.1
Sweden	28	1	3.6
United Kingdom	41	5	12.2
Total	**873**	**89**	**10.2**

Source: Authors.

3 Results and discussion

The facilities analyzed constitute a representative sample of show caves and tourist mines from the EU, of which 10.2% of the answers have similar figures to those of other studies [30]. Table 1 shows the number of activities and answers for each country.

3.1. Physical characteristics of the sites

They are located in diverse geological settings, comprising different types of rocks, with carbonate rocks being the most abundant; although, there are also examples of conglomerates (Font Major Cave, Catalonia, Spain), sandstones and shales (Clearwell Caves, Gloucestershire, United Kingdom; Speedwell and Peak Caverns, Derbyshire, United Kingdom), and volcanic rocks (La Pintada and El Viento Caves, Canary Islands, Spain). In addition, the study encompassed mines containing several types of minerals, such as the salt mines of Wieliczka, Poland, the Eugènia lead mine from Catalonia, Spain, and the Almadén mercury mines from Castile-La Mancha, Spain.

Underground tourist sites vary in length from very short, less than 7 m to more than 1 km. Moreover, most routes had a depth of less than 100 m, all of them being less than 200 m.

Another characteristic that should be considered when planning the safety monitoring system is the presence of water. As a result of karstic processes, many caves contain rivers or lakes. However, these bodies of water are not used for tourist purposes in most cases.

3.2. Visitor control

When designing a monitoring system, the carrying capacity of visitors is an important parameter to consider in terms of safety and influence of visitors to the environment among other parameters [31,32]. Fig. 3 displays the number of visitors per year in the surveyed activities and the maximum capacity of visitors at the same time. The capacity of the facilities depends on the geometrical characteristics, as well as the environmental, ecological and safety issues. The number of available guides is another factor that affects the number of simultaneous visitors.

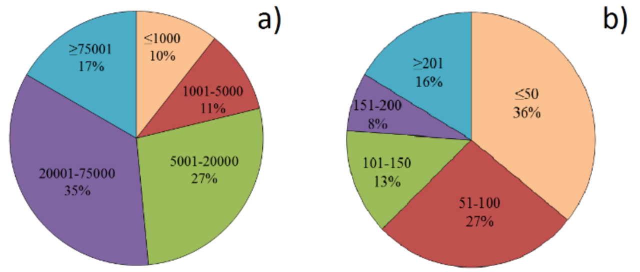

Figure 3. (a) Number of visitors per year; (b) visitors capacity of the activities.
Source: Authors.

Only 11 activities can be visited without a guide. Besides, most of them have less than 15 employees. Some managers mentioned that they would increase the maximum number of visitors if they had the right technology to do so. Most caves (85%) are accessed on foot, and only a few (15%) have other options like vehicles or lifts. The percentages reported in tourist mines were very similar, 83% access on foot and 17% by vehicles or lift.

3.3. Physico-chemical conditions

The control of environmental conditions is crucial to maintain safety levels in underground activities. Maximum and minimum mean temperatures vary between 6 and 15ºC, with some cases below 0ºC or above 20ºC. Internal combustion vehicles in underground tourist facilities can also have an influence on the environment due to the emission of various gases, including CO_2. Fortunately, its use is not common as 2% uses internal combustion vehicles according to the questionnaire.

Ventilation control is also crucial to remove the affected air and provide oxygen to humans. The ventilation system can be either natural or forced, but 14% has set up artificial ventilation.

3.4. Geotechnical control

These risks are often monitored using extensometers or other techniques [33]. Data can be recorded *in situ* or using remote servers [34], and then landslides are predicted to prevent accidents involving visitors. The developed system has been tested using the information gathered from the questionnaire.

3.5. Geoheritage

Most of the tourist sites analyzed in this study have special ecological, geological or prehistoric elements that should be preserved (for example, karst formations or ancient paintings). A suited monitoring system is crucial to preserve these elements.

3.6. Biodiversity

Many underground sites contain characteristic fauna and flora of interest that could be affected by human impact. An important parameter in this regard is illumination [35-37]. In addition, tourist caves and mines may require physical modifications to allow easy access for visitors, which could alter ecosystems and biodiversity [13,38].

4. Cases studies

The results have been used to design the monitoring system and validate it in a two-case study.

4.1. The Minilla mine (Cardona, Spain)

The tourist mine called Minilla is located in Cardona, 100 km from Barcelona. A former potash mine was closed in 1987 with only one drift accessible to the public. It is a small activity that excavates into a diaper near the surface. It was adapted to touristic visits in 1996 with a length of approximately 500 m.

Previous studies pointed out the hazard due to the existence of dolines, collapsing 70 m eventually. Hence, a network of 8 extensometers was installed in the drift to verify the security level, four in the rock mass and other four through the main fissures (Fig. 4). Each extensometer was connected by means of wires to a junction box located at the exit of the mine, where there was a central unit to detect any movement from the face or floor.

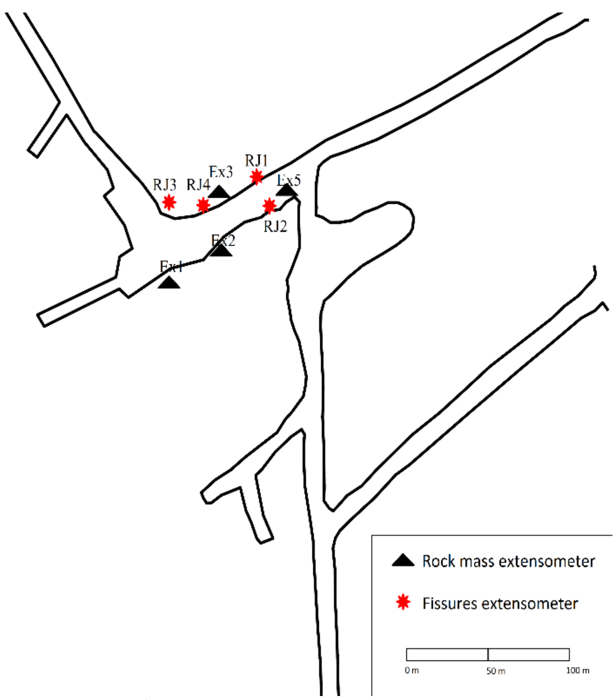

Figure 4. Scheme of the Minilla mine with the extensometers location.
Source: Authors.

The use of multiple extensometers to control floor and ceiling movements in mines and caves was successful. For this reason, the system is suggested as a useful option to control geotechnical conditions instead of traditional methods that are more expensive.

4.2 Salt Mine of Wieliczka (Spain)

The Wieliczka mine is one of the most important tourist mines in the world, receiving more than one million tourists per year. In addition, several natural caves are connected to the galleries resulting from the mining activity, such as the Groty Krysztalowe [39].

Salt mines are intrinsically hazardous and are essentially related to gas emissions [40,41]. The preliminary safety system was tested at the Wieliczka mine. The entire system was set up and tested in an underground passage for two days, checking the position of the tourists, temperatures, humidity, gas levels, geophones signal (falling rocks and ground movements) and laser detectors (ceiling, ground and walls movement). These parameters were gathered and managed by the software, obtaining positive validations in all cases. This information was obtained live and was displayed on a digital map. The tests demonstrated that the system is an appropriate tool to improve safety in underground tourist activities.

5. Conclusions

The survey has given an overview of the tourist mines and caves in Europe, their main characteristics and what the system should include to control the site. The proposed system and data gathered may help to open new underground tourist sites and boost their importance as part of the geological and historical heritage. According to the managers of underground tourist sites, the most important factors to control include: number of visitors, physico-chemical and geotectonic parameters, geoheritage care and biodiversity control. Most of the tourist sites analyzed have special ecological, geological or prehistoric elements that should be preserved. However, they may require physical modifications in order to allow easy access to visitors and alter the ecosystem and biodiversity. A balanced solution must be found to promote them while conserving their natural features.

It has also been noted that each country applies different regulations for underground activities, and there is no harmonized regulatory framework. A common EU regulation integrating administrative requirements, geoheritage, ecological and environmental issues, and safety conditions in underground tourist activities would be of great interest.

In addition, the system created has been verified as a useful tool for monitoring the safety and environmental conditions of tourist underground places. The information previously collected has been crucial to know the necessities of the system, verifying its suitability in two case studies.

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