environmental sciences proceedings

MDPI

Proceeding Paper

Tracking the Evolution of Biodeterioration and Physico-Chemical Alterations Using Microphotogrammetric Techniques in the Altamira Cave †

Vicente Bayarri [1,2] and Alfredo Prada [3,*]

1 GIM Geomatics, S.L., C/Conde Torreanaz 8, 39300 Torrelavega, Spain; vicente.bayarri@gim-geomatics.com
2 Polytechnic School, Universidad Europea del Atlántico, Parque Científico y Tecnológico de Cantabria, C/Isabel Torres 21, 39011 Santander, Spain
3 Museo Nacional y Centro de Investigación de Altamira, Marcelino Sanz de Sautuola, S/N, 39330 Santillana del Mar, Spain
* Correspondence: alfredo.prada@cultura.gob.es
† Presented at the IV Conference on Geomatics Engineering, Madrid, Spain, 6–7 July 2023.

Abstract: Caves are open ecosystems with natural microbiota, and they are generally stable if environmental conditions are stable. Some have rock art, which is generally characterized as fragile, especially when the equilibrium conditions of the hypogeum are changed. This article shows how high-resolution microphotogrammetry, supported by other geomatic techniques, allows the objective and quantifiable control of the alterations suffered by the pigment and its variation over time regarding earlier campaigns. This method, applied periodically, makes it possible to prevent and/or detect possible alterations at an early stage and improve the conditions of the conservation of the cave.

Keywords: geomatics; micro-photogrammetry; 3D laser scanning; global navigation satellite systems; bio-deterioration; rock art; cultural heritage

Citation: Bayarri, V.; Prada, A. Tracking the Evolution of Biodeterioration and Physico-Chemical Alterations Using Microphotogrammetric Techniques in the Altamira Cave. *Environ. Sci. Proc.* **2023**, *28*, 26. https://doi.org/10.3390/environsciproc2023028026

Academic Editors: María Belén Benito Oterino, José Fernández Torres, Rosa María García Blanco, Jorge Miguel Gaspar Escribano, Miguel Ángel Manso Callejo and Antonio Vázquez Hoehne

Published: 16 January 2024

1. Introduction

Cave art is generally characterized by its fragility, and it is subject to the conditions of the natural environment that contains it, as well as to anthropic activity, which often irreversibly changes the material, ecological, and environmental conditions of caves and their areas of influence. Caves are open ecosystems with natural microbiota, and they are generally stable if the environmental conditions are stable; to maintain this balance, it is necessary to avoid any change in both the interior and its surroundings [1].

In caves, deterioration processes of natural origin are inevitable and normally associated with the geological evolution of the cave and the hydrogeochemistry of the water; in contrast, deterioration processes of anthropic origin are associated with the transformations that the cave and its surroundings have undergone to conserve and protect their paintings, as well as help to increase access to and knowledge of them, their impact being irreversible.

There are different physical–chemical alteration factors that affect the conservation of the paintings, which normally are pigment-loss processes related to various factors, such as infiltration and condensation flow, water composition, relief of the support, and the relationship with the network of fractures that can lead to the disappearance of the paintings.

The Altamira Cave is an exceptional piece of cultural heritage internationally recognized as a masterpiece in the History of Art, and it was inscribed on the UNESCO World Heritage List in 1985. It is located in Santillana del Mar (Cantabria). It was discovered in 1868, and its cave art was discovered in 1879 by Marcelino Sanz de Sautuola and his daughter María. The authenticity of the cave paintings was accepted by the scientific community in 1902 [2]. It is the first cave in which the existence of rock art from the Paleolithic period was identified.

As an integrated part of the PCP (protocol n°6 "Monitoring the state of conservation") of the Altamira Cave, periodic tracking is carried out to prevent and/or detect possible alterations at an early stage. For this purpose, high-resolution photogrammetric tracking is carried out to track, over time, the different areas of both the ceiling of the Polychrome room and the rest of the cave, which, from a conservation viewpoint, are considered to be "sensitive".

This paper shows how high-resolution microphotogrammetry, supported by other geomatics techniques such as photogrammetry, 3D laser scanning, and global navigation satellite systems, as well as analyzed via digital image processing software and managed via geographic information systems, allows the alterations suffered by the pigment and their variation over time in relation to earlier campaigns to be controlled in an objective and quantifiable manner.

This method, applied periodically, makes it possible to prevent and/or detect possible alterations at an early stage and improve the conditions of conservation of the cave.

2. Materials and Methods

Caves are irregular in shape and variable in extent, so it is necessary to integrate different georeferenced remote sensing techniques to derive new cartographies and generate new information regarding the cultural heritage element [3].

The general workflow (Figure 1) of the microbiological characterization control process shows how the GNSS coordinates captured outside the cave are propagated in order to accurately geo-reference the data inside the cave.

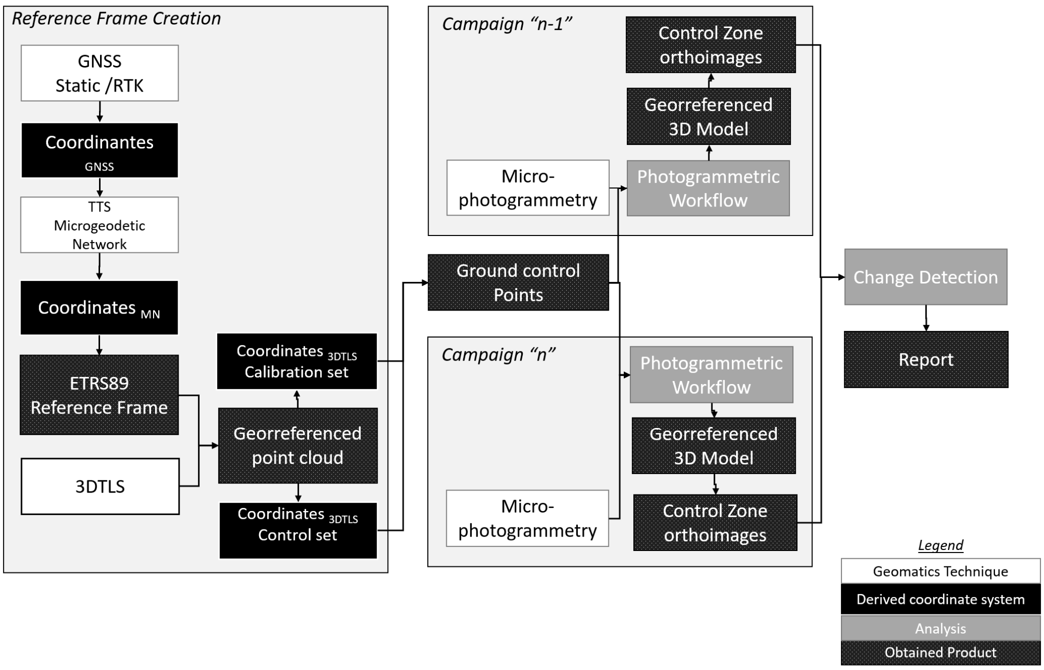


Figure 1. General workflow scheme followed in this study.

2.1. *Reference Frame Creation Technologies*

The geomatics technologies used to create the reference frame [3–5] and the derived studies [6,7], are not the subject of this article. However, a summary is given below:

Global Navigation Satellite System (GNSS): This system was used to create the reference frame, which was set to the European Terrestrial Reference System 1989 (ETRS89). In September 2013 [4], a network of 6 points was observed in static mode and adjusted using Topcon Tools, reaching a mean accuracy of 1.7 cm.

Topographic Total Station (TTS): A closed traverse was conducted back and forth within the cave [5]. The traverse consisted of sixteen stations, the total length was 430 m, the angular closure error was 0.0218 g, and the closure errors in X, Y, and Z directions were −0.001 m, −0.005 m and 0 m, respectively.

Microgeodetic Network: To create a reference system for the 3D laser scanner, 66 checkerboards were positioned around the cave, radiating from the vertices of the traverse [5]. Each target on the checkerboards was observed from multiple scan positions, and their positions were derived by calculating a free network, as described in [6].

3D Terrestrial Laser Scanning: The interior of the cavity was characterized using a FARO FOCUS X-330 scanner [8]. The transformations of each scan position were performed using iterative fitting algorithms based on the previously calculated 3DTLS reference frame, formed using the 66 checkerboards, to generate a point cloud model of the cave [6]. Each panel was scanned to obtain a 1.5 mm resolution (50% spatial correlation), and the result is two new set of points for each panel. These sets were taken directly from the point cloud and used as the Ground Control Points (GCP) and validation for the microphotogrammetry. The points in each control zone are variable, according to the extension, but the mean was 10 points/m^2.

2.2. Change Detection Process

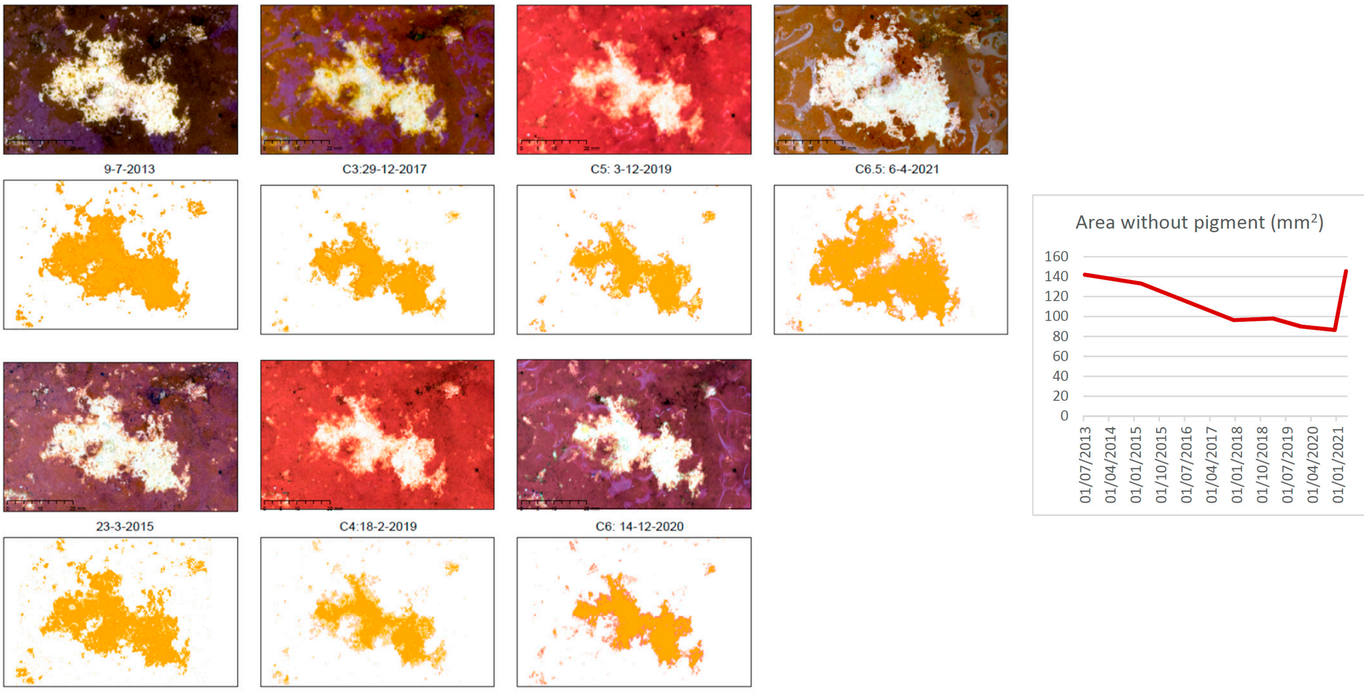
Microphotogrammetry: A Sony A7R Mark ii [9] camera with a 90 mm lens was used. The lighting used was an F&V (F&V Europe B.V., Helmond, The Netherlands) HDR-300 LED ring light with a 0.4 mm thick 0°/90° linear film polarizer and a milk filter for the ring. The generated documentation should have a pixel size lower than 50 µm × 50 µm. The average of the control areas in campaigns was less than 40 µm pixel size, which allows better definition of the outlines of fungal and bacterial colonies.

The light and the lens were polarized to reduce the glare produced by the water present in the scenes. A clipping mask was created to reduce the area of analysis to that proposed in the report. Each control zone was geo-referenced with the GCP obtained, and the mean error was lower than 1 mm.

Digital image processing: Each orthoimage is classified following an unsupervised classification method known as ISODATA [10]. It need not know the previous number of clusters, but the user must define the threshold values for parameters, and an iterative process is run until the threshold is reached. These classifications are compared to derive changes in the classified surfaces.

3. Results

This combination of technologies has allowed us to track the evolution between 2013 and 2022 in ten control areas up to 1 m^2, each one with a mean GSD of 35 mm. The changes are presented in an annual report and, as an example, the evolution in the morphology of a lagoon during this period of analysis shows that the processes of washing, migration, or dragging of the pigment are still undoubtedly active today. If we analyze the evolution of the lagoon over the last few years (Figure 2a), we can see (Figure 2b) to a large extent that the perimeter areas that delimit the lagoon's surface have been washed out.



(**a**) (**b**)

Figure 2. (**a**) Evolution of the lagoon corresponding to the area where pigment destruction was detected in 2013 due to processes associated with water leaks. (**b**) Surface area in mm^2 without pigment in the period 2013–2021 for the evaluation of the washing process.

4. Conclusions

The combined use of geomatic techniques makes it possible to determine the existence of more or fewer dynamic variations in the analyzed areas of the polychrome ceiling. Using these techniques makes it possible to detect parts associated with colonies of microorganisms, such as the appearance of new colonies, expansion and/or consolidation of colonies, increases in the thickness of colonies, displacement of colonies, and disappearance/loss of colonies and parts related to the pigment, such as displacements/migrations, variation in density, or loss of pigment.

For future comparisons, it is recommended to continue with light and objective polarization to eliminate all the glare caused by the sheet of water, maintain the resolution, and calculate the hydrography of the ceiling to adapt the control areas to them, especially in areas with the movement of elements supported by the ceiling; the aim is to achieve the correct interpretation of the relationships between water flows and the entrainment processes of both pigments and bacteria.

Improvements are also intended to be made to the change detection system. Current mainstream change detection models use encoder–decoder structures and Siamese networks. A mutual feature-aware network (MFNet) algorithm is proposed to be created.

Author Contributions: Conceptualization, V.B. and A.P.; methodology, V.B. and A.P.; software, V.B.; validation, V.B. and A.P.; formal analysis, V.B. and A.P.; investigation, V.B. and A.P.; resources, V.B.; data curation, V.B. and A.P.; writing—original draft preparation, V.B. and A.P.; writing—review and editing, V.B. and A.P.; visualization, V.B.; supervision, V.B. and A.P.; project administration, A.P.; funding acquisition, V.B. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by the Museo Nacional y Centro de Investigación de Altamira.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The research data supporting this publication are not publicly available. The data were collected by GIM Geomatics as part of the research and conservation studies of the Cave. These data are kept in the Museo Nacional y Centro de Investigación de Altamira.

Acknowledgments: The authors of this work would like to thank the GIM Geomatics company for its support of this project.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Ontañon, R.; Bayarri, V.; Herrera, J.; Gutierrez, R. The conservation of prehistoric caves in Cantabria, Spain. In *The Conservation of Subterranean Cultural Heritage*; Saiz-Jimenez, C., Ed.; CRC Press: London, UK, 2014.
2. Cartailhac, É. Les cavernes ornées de dessins: La grotte d′Altamira, Espagne. "Mea culpa" d′un sceptique. In *L′Anthropologie*; Masson: Paris, France, 1902; Volume 13, pp. 348–354.
3. Bayarri-Cayón, V.; Castillo, E. Caracterización geométrica de elementos complejos mediante la integración de diferentes técnicas geomáticas. Resultados obtenidos en diferentes cuevas de la Cornisa Cantábrica. In Proceedings of the VIII Semana Geomática Internacional, Barcelona, Spain, 3–5 March 2009.
4. Bayarri, V.; Prada, A.; García, F.; Díaz-González, L.M.; Heras, C.D.L.; Castillo, E.; Fatás, P. Integration of Remote-Sensing Techniques for the Preventive Conservation of Paleolithic Cave Art in the Karst of the Altamira Cave. *Remote Sens.* **2023**, *15*, 1087. [CrossRef]
5. Bayarri, V.; Prada, A.; García, F. A Multimodal Research Approach to Assessing the Karst Structural Conditions of the Ceiling of a Cave with Palaeolithic Cave Art Paintings: Polychrome Hall at Altamira Cave (Spain). *Sensors* **2023**, *23*, 9153. [CrossRef] [PubMed]
6. Bayarri, V.; Prada, A.; García, F.; De Las Heras, C.; Fatás, P. A Multisensory Analysis of the Moisture Course of the Cave of Altamira (Spain): Implications for Its Conservation. *Remote Sens.* **2024**, *16*, 197. [CrossRef]
7. Bayarri, V.; Castillo, E.; Ripoll, S.; Sebastián, M.A. Control of Laser Scanner Trilateration Networks for Accurate Georeferencing of Caves: Application to El Castillo Cave (Spain). *Sustainability* **2021**, *13*, 13526. [CrossRef]
8. FARO. FARO Laser Scanner Focus 3D X 330 Technical Datasheet. Available online: https://downloads.faro.com/index.php/s/z6nEwtBPDpGPmYW?dir=undefined&openfile=42057 (accessed on 11 January 2024).
9. SONY. Sony A7 R Mark ii. Available online: https://www.sony.com/electronics/support/res/manuals/W000/W0005150M.pdf (accessed on 9 December 2022).
10. Mather, P.M.; Koch, M. *Computer Processing of Remotely-Sensed Images*; John Wiley & Sons, Ltd.: Chichester, UK, 2004.