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Digital image analysis based study, recording, and protection of painted rock art. Some Iberian experiences

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ABSTRACT

This work reviews different approaches, with the common point of using digital image analysis techniques imported from the research field of environmental remote sensing, used the last years by our research group for obtaining information from prehistoric painted rock panels. The obtained results are relevant for the definition of the particular environments of different panels (the complex series of elements composing the natural systems in which the rock art constitute one of the parts, and the relations and synergies connecting all them), for the definition of the rock art itself (in terms of composition, taphonomical history or typology), or simply for improving the vision of faded images, helping in the task of making a secure tracing of the panel. This paper presents several examples in which image uncorrelation by principal components analysis, mixed digital classification, and auto-tracing helps understanding the panels.

1. Introduction

Along the last years, the utilisation of digital image analysis techniques has become a standard procedure for the elaboration of tracings of rock paintings. These kind of techniques has been considered by UNESCO as "the best fitted for the reproduction of rock art manifestations, keeping in mind that [⋯] unites the advantages of low cost and low or non-existent threat for the completeness of both the depictions and their supporting rocks" (Collado Giraldo, 2012: 46, my translation). Even, a recent paper declares that "exhaustive, integral and non-invasive documentation of rock art sites is an indispensable requirement both for their study and to monitor degradation and alteration processes, and to guarantee the preservation and authenticity of this heritage" (Domingo et al., 2013: 1880). Most applications of these techniques, nevertheless, are just focused to the obtaining of digital tracings, avoiding the documentation not only of the microtopography of the supporting rock but of the elements of the system in which the rock paintings are included (Rogerio-Candelera, 2009), thus missing an important amount of information crucial for conservation issues, as is the one supported by the interrelations (not only theoretical but physical) of the biotic and abiotic elements which allow establishing the present state of the complex natural systems, and the assessment of the relative importance of the confronted tendencies to homeostasis or entropy, i.e., the existence or not of a steady state of the system.

Natural systems including rock art have basically two kinds of location: high and low energy systems. High energy systems (open-air and sheltered locations) are those with a high exchange rate of matter and energy with the environment: high energetic oscillation, and high availability of light and nutrients for macro and microorganisms. Low energy systems (caves), on the contrary, are much more stable in energetic and material terms. The direct consequences are a selection of the local biocenosis and the establishment of different possibilities of deterioration. Thus, a low energy system, is more fragile that a high energy one, as this last one has survived to an aggressive environment maybe for thousands of years. A low impact as the presence of a small group of visitors in front of a rock panel inside a cave, on the contrary, may generate variations in temperature and humidity higher than the offered by the natural conditions of the cave in a complete yearly cycle (Sanchez-Moral et al., 1999, 2000).

Another question, and not of lesser importance, is what can we understand under the definition of "digital image analysis" or "digital image processing". For older authors, the terms *manipulation* and *subjectivity* are commonly included in their definitions: Thus, for Sabbins (1987: 433) digital image processing means "computer manipulation of the digital-number values of an image"; for Lillesand and Kiefer (2000: 470) "involves the manipulation and interpretation of digital images"; or for Mulders (1987: 151), whose concept of image enhancement relates to "the modifications of an image to improve its quality as perceived by

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a viewer. The criterion is subjective and the enhancement is judged by the observer". Other definitions (Rogerio-Candelera, 2010a:121, my translation) emphasize the scientific side: "the set of mathematical operations effectuated with the matrix images obtained by every type of sensor". This is reflected in the common practice of "digital image analysis/processing" applied to rock art, that commonly lie in the first kind of definitions as it is usually based on the use of software developed for image retouching, as Photoshop, PhotoPaint, Paintshop or Gimp, not for image analysis, and consequently with a limited set of analytical possibilities. Nevertheless, there are some digital image analysis applications that fall in the "scientific" part of the definition, developed in the last years: most of them using the DStretch plugin to the software ImageJ (Harman, 2008), specifically designed for the automation of the enhancement of rock paintings by using the Decorrelation Stretch technique (Gillespie et al., 1986), which essentially consists in the calculation of the principal components of the image and the elaboration of colour composite images using the resulting bands. Other researchers have also used principal component analysis (PCA) for the enhancement of rock paintings, directly (Vicent García et al., 1996; Mark and Billo, 2006), or include it in the design of new software tools for these purposes (Hollman and Crause, 2011,; Cerrillo-Cuenca et al., 2014). Most archaeological applications of the technique are nevertheless addressed to satellite remote sensing (Lasaponara et al., 2012; Traviglia and Cottica, 2011, as examples). Basically, PCA consists in the linear transformation of the data codified in the bands of a multispectral image (i.e. the DNs, "digital numbers" or "pixel values"), in order to elaborate an image referred to a new reference system of normal axes (i.e., uncorrelated). This result is reached by means of the rotation and/or translation of the axes of the original feature space (Lasaponara and Massini, 2012).

Other useful approaches for the detection and mapping of the painted surfaces in rock art consist in the application of a mixed supervised and unsupervised classification strategy, i.e. the assignation of every pixel of an image to a category based on the spectral behaviour of the pixels, automatically (unsupervised) or by means of specific training areas (supervised) (Buchner et al., 2000), or even multispectral recording (Robinson and Ware, 2002), a promising tool not still widespread in the rock art research community. The purpose of this paper is to review some recording experiences conducted by our research group along the last decade, understanding them not as finished results, but as steps in a way under construction. These experiences are addressed to the integral recording of those elements of natural systems harbouring rock art which exhibit a cartographically representable dimension. Some of the reviewed experiences have been published in other places, but some others remained unpublished or published in a very partial way. The first group of experiences will only receive a brief reference in the text, as the complete data are publicly available. The second group of experiences will be treated more extensively. Our interest in this paper, with the publication of unpublished and not always successful approaches, is to contribute to the development of the research field with the publication of both positive and negative results.

2. A soft review of our published experiences

Our experience in rock art recording using digital image analysis begin at the mid-2000s, when trying to develop instrumental techniques allowing the non-invasive characterization of complex natural systems including rock and mural paintings, with a special interest in the biogenic and cultural (the art itself) coverages. The direct cause was the implication of our Research Group in two contracts directed to the conservation of two important subterranean components of Cultural Heritage: the Roman necropolis of Carmona, Southern Spain, and the widely known Altamira cave, in Santillana del Mar, Cantabria, North Spain. Our first experiences applied PCA in order to achieve two different goals: (i) to improve the visualization of the coverages of interest, and, (ii) to monitor processes quantifying their results both in absolute and relative terms. At Circular Mausoleum, a Roman subterranean tomb in which a microbial consortium dominated by a *Streptomyces* species produced a diffusible violet pigment on the walls, the stains were monitored by a modification of a technique currently used to quantify burnt surface in brush fires by satellite imagery that implied the elaboration of temporal series of photographs and the application of PCA (Rogerio-Candelera et al., 2008). An improvement of this technique was used in the Altamira cave in order to detect, differentiate and monitor the development of three types of microbial colonisations threatening the Palaeolithic paintings along a period of three years (Rogerio-Candelera, 2010b). In this case, the information obtained from PCA was complemented with that obtained by means of algebraic operations with images. Under laboratory conditions, research on detecting, measuring and assessing the role of the biological component of these kinds of systems was also conducted in Miller et al. (2010a,b, 2011).

On the other hand, the accurate visualization and recording of the cultural coverage of the panels by PCA was explored in laboratory experiences, thereafter tested in real targets, as that of the Roman tomb of Three Gates (Rogerio-Candelera et al., 2011), the Levantine paintings of *Muriecho*, at Huesca province, Northern Spain (Portillo et al., 2008), or the complex panels of *La Coquinera II* at Teruel province, Spain (Rogerio-Candelera et al., 2009).

During these and the next years, supported by a CSIC project coordinated by J. Vicent (*Métodos analíticos para la documentación integral del arte rupestre prehistórico*/Analytical methods for the integral recording of prehistoric rock art) and a Consolider-Ingenio programme coordinated by F. Criado (*Programa de investigación en Tecnologías para la Conservación y revalorización del Patrimonio*/ Research programme on technologies for the conservation and revalorization of Cultural Heritage), we were able to develop the working protocol that is on the basis of our work, and to apply systematically this approach in order to develop detailed integral tracings of the *La Hoya* Hall, at Altamira Cave, Spain (Rogerio-Candelera and Élez Villar, 2010), *Faia* post-Palaeolithic rock paintings (Rogerio-Candelera et al., 2010), and *Cachão da Rapa* painted panel (Rogerio-Candelera et al., 2013), both in northern Portugal.

Along these years, the subjects covered by our research include the mapping and quantification of biofilm growth; the differentiation of microbial colonisations using visible and induced fluorescence photographs, quantification and monitoring of the process; to improve visualisation and detect non visible motifs; to differentiate pigments in cumulative scenes, to differentiate coverages implied in the conservation of the panels; to elaborate vector tracings; to detect important conservation problems as the endolithic growth in stone substrates; and to monitor the development of biofilms, in general.

The list of rock art sites studied, although unpublished (or at least, as we said before, without a complete publication), includes *Cueva del Arco* and *Cueva del Encajero* shelters, in Andalusia, and also *Cabras Blancas*, and *Tio Campano* shelters in Aragon. In the following pages we will support some information about the techniques used and the results achieved.