CLOSE RANGE PHOTOGRAMMETRY AND ENHANCED RECORDING OF PALAEOLITHIC ROCK ART

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ABSTRACT:

Recording of archaeological sites has long been studied by many scientific organizations. However, the analyses and evolution of human beings through rock art is one of the most challenging tasks in prehistoric archaeology, not only because of the unpredicted contribution to the understanding of the past but also because of the difficulties for appropriate recording. Tracing, rubbing and photography are traditional techniques used to provide just two-dimensional results many times in combination with digital image processing. But often, they lack in accuracy depending on size, roughness, complexity of the site, means and experience. This paper deals with the recording of a Palaeolithic rock art panel with complex, tiny, shallow and faint engravings, hardly difficult to record by traditional techniques. For this purpose, a combination of close range photogrammetry, multiband photography with varying incident light and advanced image processing tools, including merging, principal components analyses and colour balance has been used. It allowed us to generate an ortho-image mosaic best adapted to the steep digital model of the panel as well as a metric composite enhanced imagery characterizing the whole set of engraving. The potential of the developed approach will be illustrated by reference to the Palaeolithic rock art motifs of Meravelles Cave (Valencia, Spain). Additionally, a photo-realistic model has been carried out to show the Palaeolithic motifs in 3-D.

1. INTRODUCTION

The analyses and evolution of human beings through rock art is one of the most challenging tasks in prehistoric archaeology, not only because of the unpredicted contribution to the understanding of the past but also because of the difficulties for appropriate recording. Unfortunately, unique rock art motifs either rock engraved or cave painted have been partially or totally destroyed over the centuries due to weathering conditions, erosions, natural disasters and human interventions, e.g. unpredicted conservation or restoration practices, uncontrolled visits, illegal trade in antiques and, last but not least, vandalism. Besides, many other sites are continuously being discovered. Therefore, precise documentation is a basic requirement properly set up in many cultural heritage charters (Venice Charter, 1964; ICOMOS Charter, 1990) and in national conservation and restoration policies.

Nowadays, it is possible to find literature facing recording, visualization and reconstruction issues for cultural heritage from different points of view: technology, different approaches, data acquisition, mobile mapping and site mapping, archaeological landscapes, visualization, reconstruction and animations (Baltsavias et al, 2006). All these topics are well-addressed by many international organizations such as the International Committee for Architectural Photogrammetry (CIPA), http://cipa.icomos.org/; the International Society for Photogrammetry and Remote Sensing (ISPRS) Commission V, http://www.isprs.org/technical_commissions/wgtc_5.html; and the International Society on Virtual Systems and Multimedia, http://www.vsmm.org/.

Tracing, rubbing and photography are traditional techniques used to provide just two-dimensional results many times in combination with digital image processing. But often, they lack in accuracy, depending on size, roughness, complexity of the site, means and experience. Besides, a cost-effective close range photogrammetric procedure has been carried out to metrically record the Palaeolithic engraves in a similar way as proposed by (Chandler and Fryer, 2005; Chandler et al, 2005). A self-calibration bundle adjustment was performed in order to get the inner and outer orientation parameters of our non-metric digital camera. Therefore, we did not follow the traditional stereo pair orientation procedures as followed in some petroglyphs by Miranda and Altrock (2005). Furthermore, the possibility to apply laser scanning systems for this survey was also considered, specifically the range of high resolution ones. Barnett et al (2005) obtained successful results applying a triangulation laser scanner for recording and monitoring rock art erosion in opened moorland, exposed to prevailing weather. The surface of the recorded rock was engraved with over 60 individual cup marks each between 1.0 and 0.5 cm in depth. However, it should be pointed out that in our work a set of tiny and shallow engravings (inferior to 0.3 mm both in width and in depth) carved on stone would have required the maximum resolution available at present only in a few triangulation laser scanners. Therefore, the chance of finding triangulation lasers with an appropriate footprint resolution was minimal. Additionally, the difficulties of accessing the site (following a steep animal trail up to the cave) as well as the weight of the equipment, on the one hand, and the archaeologists' needs of comprehensive photograph recording, on the other, encouraged us to apply close range photogrammetric techniques.

For the purpose of recording the archaeological target, a faint Palaeolithic rock art panel, photogrammetric techniques were applied in order to capture maximum tracing details on hardly visible engravings. The methodology not only involved photogrammetric recording but also image fusion after changing illumination conditions, orthoimagery production on a steep slope model as proposed by Buchroithner (2002), and image enhancement after principal components analysis as recently mentioned by Mark and Billo (2006). Additionally, a photo-realistic model was carried out to show the Palaeolithic motifs in 3-D.

2. THE ROCK ART SITE

The rock art site chosen to undertake the recordings is situated on Falconera's Mountain range in Gandia, Valencia (Spain). The area is renowned because it is placed nearby Parpalló Cave, one of the most important European collections of Palaeolithic mobiliar rock art on rock tablets (Villaverde, 1994).

Meravelles Cave is an irregular and middle size limestone cave, with approximately 15m x 40m x 10m (in width, depth and height) at the centre. It was discovered during the end of the 19th century, although the existence of the indoor Palaeolithic engravings was unknown. So far, there are only four caves showing Palaeolithic Parietal style engraves or paintings and one engraving shelter in Valencia region (Villaverde et al, 2004; Villaverde, 2005).

The indoor surface where the Palaeolithic engraved motifs are placed is a hidden area 3.5 meters above cave's ground. Its surface is continuous and double-curved, although there is a micro topography due to deposits such as sediments, minerals and last but not least stalagmites. The engravings size is about 1 m x 1.3 m x 1.2 m (Figure 1). It has been recently restored in order to put out all the layers covering up most of the engravings although future intervention campaigns are predictable. After this process of restoration, three different areas were identified: one superior area, holding a complete engraving horse, one incomplete animal and some lines; one central area, the richest area, which holds two horses, two goats, one stag, one hind, two urus and three undetermined animals; and one inferior area, showing only one horse (for the time being). Within the latter two areas, the identification of hundreds of tinny lines, unstructured, together with some visible signs could symbolize new motifs in the near future.

When analysing the panel, it is possible to identify two different epochs. The oldest one, dating back to either the Lower or the Middle Solutrean (21.000-20.000 CBE), is characterized by disproportionate engraves and a lack of anatomic modelling for the motifs. The second epoch, dating back to the Upper Solutrean (about 18.000 CBE), is characterized by both clear lines and careful anatomic details, and would include three figurative representations.

Figure 1. Overview of the Palaeolithic rock art panel in Meravelles Cave

3. RECORDING ROCK ART BY DIGITAL AND CONVENTIONAL MEANS

Nowadays, recording of painted rock art is carried out by means of tracing through digital image processing. The use of commercial graphics software such as Adobe PhotoShop and CorelDRAW allows the distinction between pigment and rocky support (Montero et al, 1998; Cacho and Gálvez, 1999; Clogg and Díaz-Andreu, 2000; López y Domingo, 2006). However, this technique is not appropriate when Parietal art is carried out with both thin and complex lines, due to illumination problems when willing to visualize all lines in only one image. Other related problems are surface shadows from micro topography as well as engravings trajectories when there is irrelevant colour contrast. Because of that, making a tracing of the engravings by laying a sheet of plastic paper over the stone and marking on with a black marker pen is one of the procedures carried out in Meravelles Cave. The consolidated stone's surface, without any danger of alteration, allowed the application of this technique as in some other foreign Parietal sets with tiny engravings (Zilhão, 1997).

Figure 2 displays a preliminary tracing obtained by traditional means in Meravelles Cave. It shows three animals: firstly, urus' head is looking left, with closed snout, long face, horns in biangular perspective, and a detail of an ear; secondly, another urus' head, below the previous one, looking up, with obvious narrowing snout and rectilinear tracing horns; and thirdly, a stag, with two linearly reduced and opened horns, and an incomplete head.

Figure 2. Traditional tracing result of many thin and complex Palaeolithic rock art engravings

4. PROPOSED APPROACH FOR RECORDING FAINT PALAEOLITHIC MOTIFS

The proposed approach presented herein addresses issues identified above. Since every site or rock art panel is different, especially in the quality and quantity of engravings, the developed technique is general and can be applied to any panel or motif faint or difficult to decipher, and with any digital camera. Specifically, the technique will allow:

- To acquire the photographs with any camera, although high geometric resolution is recommended.
- To merge and reference any set of images shooting to the same target.
- To create the best orthoimagery layers when the digital surface model is provided.
- To enhance faint engravings after projecting all the radiometric pixel information on uncorrelated axes.

Our technique combines surveying measurements with a reflector-less total station and a photogrammetric bundle adjustment using home-made artificial targets on the panel. The details of the approach are given in the next sections.

4.1 Artificial targets

Unfortunately, the painstaking sticking of self-adhesive targets over the entire panel was required due to various reasons: firstly, to set up the object space reference system; secondly, to merge multiple images with different incident ‘hard’ light (some picture sectors were very bright and some very dark); thirdly, to mosaic overlapped images; fourthly, to guarantee precise measurements; and fifthly, to limit error propagation on the different steps. All the targets were carefully placed over the panel in order to avoid engravings. A regular grid shape pattern of black-and-white squared patterns was set up. Additionally, two squared shapes were selected: small ones, 3 mm squared targets placed every 8 cm; and large ones, 70 mm squared targets placed every 32 cm (Figure 3).

Figure 3. Enlarged image showing faint engraves as well as artificial targets over the panel

4.2 Photography

Although there are no rules for selecting a specific camera for heritage documentation, analysing some criteria suggested by Grussenmeyer et al (2002) such as both the smallest object detail and the requested accuracy of the final model, on the one hand, and the mobility and flexibility of the image acquisition system, on the other, a high-resolution small-format SLR digital camera was selected. Specifically, a 12.4 Mega-pixel Nikon D2X body and a Nikkor 50mm f1.4 lens were used to record the indoor rock art motifs. Moreover, a 300 W halogen lamp provided enough light to take all the pictures without flashlight.

Close range photography (almost macro photography) of the motifs was required to bring out all the faint engravings. Therefore, the panel was split into seven rows and four columns. The camera-object distance was approximately 30 cm for all the twenty-eight projection centres, and 1:6 the average image scale. Furthermore, the engravings shadows of different images allowed us to discriminate among image features with some characteristic patterns of luminance variations. Thus, a formal analysis of the engravings should consider the relevant shadow variations. For this purpose, a low-level incidence light (i.e. ‘hard’ light) from the four main directions (Figure 4) was set up in order to emphasize the superimposed motifs. Therefore, these images did not require a background illumination to decrease the micro topography shadows of the stone. The before-mentioned statement made our illumination strategy slightly different to one pointed out by Jobst (1999).

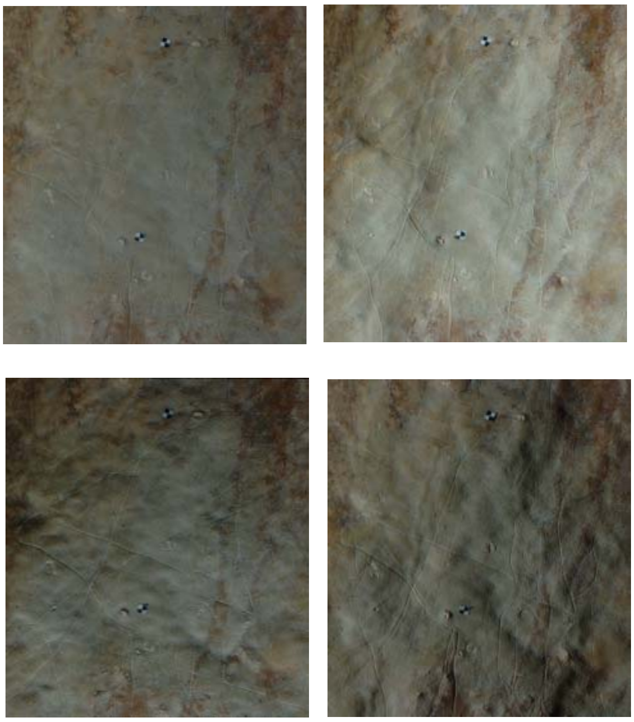

Figure 4. Images collected with incident hard light. Directions: top left) N-S, top right) E-W, bottom left) S-N, and bottom right) W-E

Additionally, a set of 35 convergent images was used to perform an 'in-situ' self-calibration bundle adjustment. The photographic recording finished after a single stereopair was acquired for each patch; a base to distance ratio of 1:10 was selected. The orthogonal stereoscopic images might constitute a valuable piece of information for future interventions. All these convergent and normal images were taken with even illumination.

4.3 Surveying

The use of good co-ordinated control points is essential because the image cannot be adjusted into its true position without accurate referencing points (Bryan et al, 1999), unless either direct orientation is used or a free bundle adjustment is worked out. In our case, it was not possible to make use of GPS/INS sensors inside the cave, but 25 well-distributed and three-dimensional targeted points were measured by means of a reflector-less total station.

4.4 Photogrammetric data processing

The use of a non-metric camera required the determination of the inner orientation parameters in order to achieve maximum accuracy on the final orthophoto mosaic. For this purpose, an in-situ self-calibration bundle adjustment (Fraser, 1997) was carried out with the convergent images. FotograUPV software developed at the Department of Cartographic Engineering, Geodesy and Photogrammetry, Polytechnic University of Valencia, was used to derive the principal distance, principal offset and radial lens distortion parameters. From the bundle adjustment, all the small artificial targets were co-ordinated in 3-D, summing up to 147 points (Figure 5). The automatic intensity-based matching algorithm failed to deliver a more detailed digital surface model, because of both the lack of texture and the colour homogeneity of the surface's stone. After the photogrammetric point measurements, a Delaunay triangulation was computed to determine the mean normal vector model of the steep digital surface model (N vector, Figure 5).

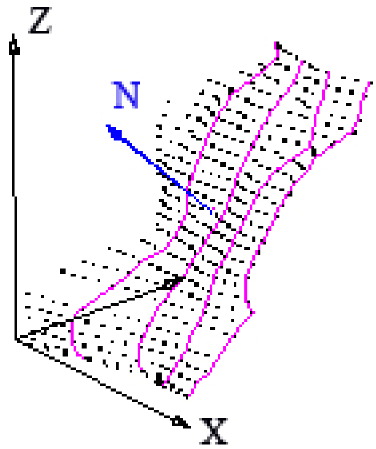

Figure 5. Steep digital surface model of the panel

Afterwards, the XYZ object co-ordinates were rotated around X and Y axes in order to obtain a levelled digital surface model (LDSM) of the whole panel, Figure 6. Obviously, the new obtained normal vector, N' vector, is parallel to the Z' axis.

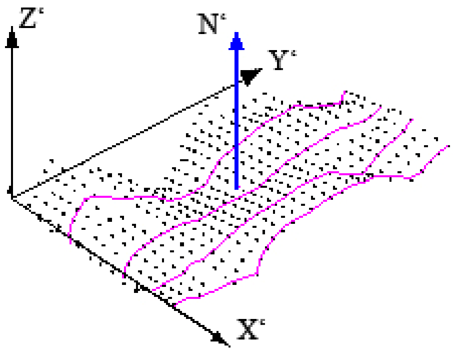

Figure 6.Levelled digital surface model of the panel

This new X'Y'Z' co-ordinated reference system was used to finally compute the exterior orientation parameters as well as the ortho-images for the twenty-eight patches. Following this way, possible smearing of the ortho-image texture was prevented in advance, based on the LDSM. Furthermore, as all the relief and tilt image displacements were corrected for the ortho-image production, the final orthoimagery were providing metric qualities to build up engravings' maps.

4.5 Digital image processing

Firstly, the whole collection of colour images with four different incident light directions was converted to black-and-white in order to reduce image size, before further processing. Secondly, the set of black-and-white images was merged and resampled to the colour patched images acquired with even illumination. After image extraction, 7 x 4 multiband images (with 5 channels each!) were compiled. Thirdly, principal components (PC) analysis was used to reduce the data redundancy effectively through transforming the data from either multispectral or multiband space to the eigenvector space. Moreover, the principal axes of principal components analysis derived from linear combinations (of input channels) do not correlate (Girard and Girard, 2003). This alternative is not very common on rock art (although it is just mentioned by Mark and Billo, 2006), despite of its frequent application in satellite remote sensing (e.g. Armenakis et al, 2003).

From Table 1, it is noted that the first three components contain over 93.3 percent of the total variances. Similarly to the usual way of applying principal components in which data variability has to be preserved for discrimination purposes, the third principal component (PC3) was selected to collapse the multiband image down to only one band as well as to represent all the engravings (Figure 7). Therefore, this resulted in a reduction of data dimension and reduced the amount of data to be handled.

Band	Eigenvalue	Percentage
PC1	2260.87	44
PC2	1419.55	28
PC3	1092.28	21
PC4	228.40	5
PC5	114.25	2
Total	5115.36	100

Table 1. Eigenvalues obtained after PC analysis

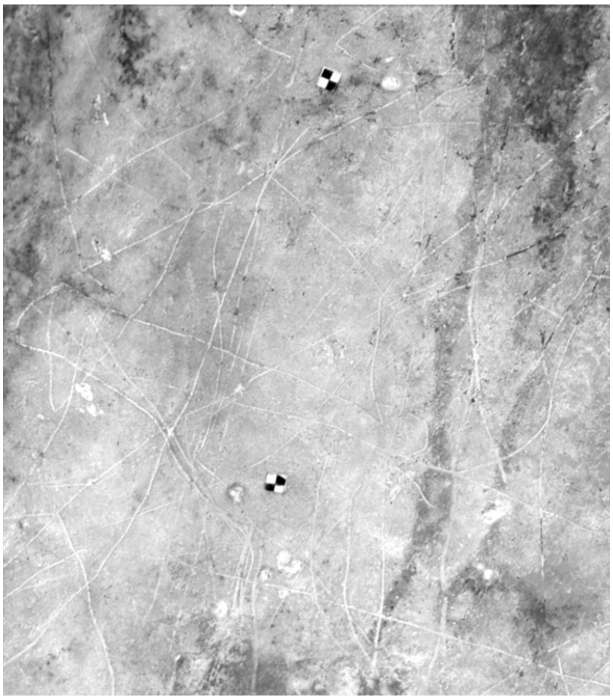

Figure 7. PC3

However, PC3 was further transformed in order to stretch radiometric values. Specifically, a logaritmic transformation was used to spread out the low pixel values and compress the high (Figure 8). Thus, details in dark areas were made more visible at the expense of details in the bright areas.

Figure 8. Enhanced PC3 after logarithmic transformation

A final composite black-and-white orthophoto mosaic was produced after enhancing the PC3 corresponding to all the 28 orthoimage patches (Figure 9). Unfortunately, the mosaicking production required extensive radiometric balancing due to image texture enhancements on individual patches. After image processing, the final orthophoto mosaic was both as useful as a picture and as precise as a map.

Figure 9. Digital orthophoto mosaic of the whole panel

This digital orthophoto mosaic was used for three main tasks:

- Firstly, to set up a scaled reference frame where it is possible to analyze, visualize, extract and plot faint and complex Palaeolithic rock art engravings.
- Secondly, to merge all the sheets of either plastic or paper with traditional tracing all together onto it.
- Thirdly, to drape texture over the digital surface model previously created to model the panel with the engraved motifs.

4.6 3-D visualization

A 3-D model is very often an important tool for visualization and data analysis, even more when the scene is undulated and non-planar. Besides, it allows us to understand the complexity of the scenario in a similar way as if you were on the site. For this purpose, we produced a photo-realistic 3-D model draping both colour and black-and-white orthophoto mosaics over the digital surface model. Figure 10 shows an interactive visualization in colour through Cortona VRML browser.

Figure 10. Overview of the photo-realistic model of the panel

The possibility of analysing the panel from different attitudes opens up the way of studying the motifs, not only from a pre-historic point of view but also from an ergonometric one. And, last but not least, this way of presenting rock art motifs makes easy the dissemination and divulgation of our cultural heritage legacy to the world by means of multimedia products and Internet.

5. DISCUSSION

The proposed approach for recording faint Palaeolithic motifs provided us a couple of images (visible and black-and-white) ready for study and interpretation (e.g. Figure 8). A number of different techniques has been used to both reference and enhance tiny and complex motifs. On the one hand, photogrammetric techniques allowed us to merge as well as to differentially rectify all the set of multiband images. On the other hand, digital image processing techniques especially principal component analysis allowed us to enhance complex, tiny, and superimposed motifs visible only with difficulties under special illumination conditions. Therefore, the generation of only one visible orthophoto image (for example from an even illuminated image, Figure 3) would be non-sense for archaeologist because that piece of information would not allow them to extract engravings. On the contrary, enhanced images properly showing engravings without image displacements due to both relief and spatial attitude would only constitute a collection of enhanced images with lines or shapes but without geometric continuity. This latter statement is even more obvious when freehand drawing, one very commonly used method of rock art recording, is carried out alone (Brayer et al, 1998).

We should emphasize that the proposed approach makes possible a greater depth of the study of the relationship between the motifs and the scenery, both in 2-D and in 3-D. Besides, the information developed for this study can be easily updated after future restoration campaigns; only the piece of restored area should be reprocessed.

6. CONCLUSION

Close range photogrammetric recording, the enhanced visualization of faint, tiny and complex engravings in 2-D, the generation of an appropriate orthophoto mosaic for the steep digital model, and, last but not least, the photo-realistic 3-D model, presented altogether, constitute a novel approach on rock art recording. Low-cost close range photogrammetric methods enabled us to carry out the metric documentation in relatively short time. Furthermore, the derived products prepared the imagery for additional digital image processing, without worrying about image displacements and lack of both geometric and radiometric consistencies.

The complete ortho-imagery with the whole collection of lines, encourages both archaeologists and recorders to further find out and analyse new engravings which could constitute new motifs. This new approach allows not only to quantify but also to study the diversity of shapes and motifs hardly difficult to examine with other local and inaccurate techniques.

Besides, the approach presented herein does not exclude other recording techniques. On the one hand, past and present results coming from either manual tracing or photographic databases could be resampled to the final orthophoto mosaic. Additionally, ortho-imagery can be printed out and be used at site. On the other hand, it can support visible image texture whenever future techniques come. It would be very useful to integrate our results with contemporary approaches such as ultra-short distance 3D digitizers and multispectral imagery. In any case, research studies should provide in the end, simple, fast and low-cost tools to record archaeological cultural heritage.

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