Recording and modeling Paleolithic caves through laser scanning

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Abstract

This paper deals with the application of a non-destructive technique, terrestrial laser scanner, for the recording and modeling of rock art at caves. Two emblematic paleolithic caves have been tested using this technology: 'Las Caldas' cave, declared Good of Cultural Interest in the 70's and nowadays, Protected Natural Area; and 'Peña de Candamo' cave, declared National Monument from the XXth century beginnings. Both caves share the same geographical context, the north of Spain (Asturias region), and belong to the most brilliant Upper Paleolithic period: Middle Magdalenian (ca. 14,000 BP). As a result, a metric laser model is generated which allow to the prehistorian works in three different levels, integrating different datasets belong to Paleolithic Art. From a basic level based on a metric 3D support with points cloud and polygonal models to a digital archiving of rock art at caves and even the development of virtual and interactive environments.

1. Introduction

The recording, modeling and visualization of Cultural Heritage is always an interesting issue for the Scientific Community (IEEE, CIPA, VAST, Eurographics, EPOCH EU, ICOMOS, ISPRS). The multidisciplinary research involved in these institutions concerning both to Cultural Heritage Informatics and use of technology, provide the prospect for the opportunity for a broad cooperation focused on the promotion and dissemination of Cultural Heritage knowledge.

Recording rock art detail through classical techniques such as drawing, tracing, rubbing or photography suffer from several drawbacks. Free hand drawing over the surface (Figure 1) is simple, easy and low-cost technique providing only a two dimensional drawing which is generally inaccurate [4]. Once the visibility of the petroglyphs (rock engravings) is assessed the next step is to trace the figures. The easier and best way to record a petroglyph is to use transparent plastic field sheets, commonly cut to standard sizes (Figure 1). Tracing on plastic sheets is commonly adopted but the method creates large volumes of media which have to be photographically reduced for more efficient storage and manually joined with the others to obtain the complete surface. The placing of a grid over the object and transferring detail one square at a time solves the physical reduction problem directly, but again requires time and patience in the field and inaccuracies are inevitably introduced. It is also invasive, requiring the physical touching of the art and requires extensive field time [6].

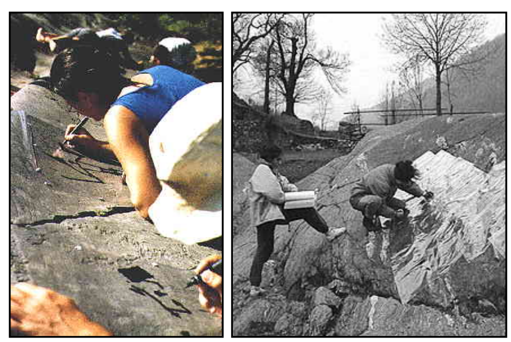

Figure 1: *Free hand drawing and tracing on plastic sheets.*

Other recording techniques, such as rubbing (or frottage) are not as precise as tracing: the superimposition within the figures and the distinction between the carvings and the natural fractures are often not clear. In any case the frottage, if repeated continuously on the same figures, can be considered a destructive technique, and can cause the abrasion of the pecking (Figure 2).

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Figure 2: *Rubbing (or frottage) in rock art recording.*

More recently, digital photography and computer tools have improved the process. Thus, the prehistorian can see photographic results almost instantly and the photos can be quickly transferred to a computer in the field. Furthermore, through Photogrammetry metric measurements can be extracted from photographs, obtaining an image corrected from lens and perspective distortion. A scaled drawing can then be made on the computer directly from the corrected image (Figure 3).

Figure 3: *Metric drawing obtained through digital images and photogrammetric techniques.*

In this context, photogrammetrists have developed several approaches to record rock art in 3D: from the classical techniques based on stereoscopic vision to multiple image-based modeling supported by bundle adjustment. Nevertheless, although digital photographic taking remains universal and low cost alternative, particularly for simple recording and qualitative use, the extraction of quantitative data from photographs is less common in the rock art framework where the fieldwork conditions are very specific and the geometry presents great complexity, requiring time, skill and knowledge related to Photogrammetry. In this sense, in a series of related projects, [10] and [8] demonstrated the benefits of Photogrammetry, for recording rock art, particularly pictographs (cave paintings). Fieldwork was conducted at a series of sites around Australia and their 'Handbook of Photogrammetry' was a key text of its day describing how to conduct a photogrammetric survey for field archaeology. More recently, [9] has continued to demonstrate the benefits of Photogrammetry to a wider archaeological audience including the Ayutthaya temple in Thailand (1999) and the Olympiad. In these two examples, an important final product has been the virtual model, enabling the visualization of the site from any perspective.

Nowadays, the emergence and improvement of terrestrial laser scanner has provided a new approach for the recording and modeling of rock art, as well as a multidisciplinary framework where professionals and researchers with a different background have the opportunity to take part. Particularly, the application of this new technology at paleolithic caves represents a specific case with a special relevance since caves preservation results vulnerable to subsequent events, agents and processes. In this fieldwork [2] also demonstrated the potency and use of laser scanner for rock art recording, especially when is combined with digital high-resolution cameras. In [5] the authors merged geometric data derived using a laser scanner with radiometric data obtained using a digital camera to generate a virtual model of an aboriginal pictograph site at the Baiame cave in Australia.

This paper deals with the recording and modeling of two emblematic paleolithic caves using a non-destructive technique, terrestrial laser scanner. With this aim, the paper follows the next structure: section 2 is focused on describing the most relevant aspects related to the different archaeological campaigns performed at both caves; section 3 shows briefly a description about the sensors used for the recording; section 4 describes the methodology developed and the results obtained for the recording and modeling at paleolithic caves; a final section is devoted to put across several conclusions as well as future perspectives.

2. 'Las Caldas' and 'Peña de Candamo' caves: archaeological performances

'Las Caldas' cave. 'Las Caldas' cave is situated in the right side of Nalon's Valley, in a small village well known as Priorio six kilometres far from Oviedo (Spain). The main entry is oriented towards the south-west, in the low part of a valley transited by 'Las Caldas' river. The surface of the cave is around 25 m^2 composed by a main corridor with two different enlargements.

‘Las Caldas’ cave was excavated by Mª Soledad Corchón and her workgroup in 1971-1973 and 1980-2000 [3]. As paleolithic settlement the relevance of this cave is focused mainly in the collections that have been discovered which belong to the most important ones related to Mobiliar Art in Europe, dated at Middle Magdalenian period. These collections gather quality and unique pieces such as petroglyphs or pictographs engraved over stones, bones or even ivory (Figure 4). The parietal engravings, located at cave’s lobby, appear sliced due to the slip of lateral walls, happened during the sedimentation of the levels belong to Middle Solutrean. This circumstance – the possibility of dating, through stratigraphy, the petroglyphs- constitutes a not very common case in the Paleolithic Parietal Art.

Figure 4: *Some pieces discovered at ‘Las Caldas’ cave.*

‘Peña de Candamo’ cave. ‘Peña de Candamo’ cave is situated in the top of a lime hill dominated by Nalon’s Valley, with a main entry oriented towards the north-west. The cave presents three different halls or levels: ‘La Gran Sala’ a big hall situated 60 meters far from the main entry; ‘El Camarín’ a hall situated 20 meters above the big hall; ‘La Sala Baja de los signos rojos’ a small hall situated near the main entry which preserve linear strokes and punctual marks with a difficult dating.

‘Peña de Candamo’ cave was discovered by E. Hernández Pacheco between 1914 and 1917 [7], who found several carved stones with an indeterminate chronology. It was really difficult at first time to extract a reliable dating, since the cave hardly preserved vestiges of an archaeological deposit of occupation. Nevertheless, thank to the archaeological performances in a near cave by the own Pacheco, several pieces belong to Solutrean Industry were discovered. After that, in the 50’s the excavations performed by F. Jordá demonstrated the existence of vestiges belong to the Lower Magdalenian and to the Upper Solutrean periods, epochs which coincide with the petroglyphs and pictographs discovered at ‘Peña de Candamo’ cave. Therefore, the parallelism and convergence between both caves were evident.

More particularly, the engravings founded in ‘La Gran Sala’ -pictographs and petroglyphs in red and black colors-, are located on a big panel in the right side of the big hall, well known as ‘Muro de los Grabados’ or Engravings Hall, and on two smaller panels, one in the left wall, with a goat’s pictograph, and the other one in the right side with a horse’s pictograph in red color (Figure 5).

Figure 5: *Engravings Hall at ‘Peña de Candamo’ cave.*

3. Multi-Sensor description

In order to accomplish the data acquisition as well as the data processing the following equipment is used:

- A medium-range terrestrial laser scanner based on time of flight principle, Trimble GS200 (Figure 6), which incorporates a rotating head and two inner mirrors (one concave and fixed and the other planar and oscillating). Trimble GS200 allows to acquire a scene with a large enough field of view, i.e. 360º H x 60º V, reducing the need of using lots of scan stations. Nevertheless, in order to overtake vertical range limitation, a geared head, Manfrotto 400, was adapted to laser scanner (Figure 6). The sensor accuracy is below 1.5mm at 50m of distance with a beam diameter of 3mm. Furthermore, the laser allows to acquire reflected beam intensity and RGB colors.

- A high-resolution camera, Sony DSC F828 (Figure 6), which allowed us to overcome the poor color information obtained from terrestrial laser scanner (768 x 576 color resolution).

Figure 6: *Trimble GS200 laser scanner and geared head Manfrotto 400 (red circle) and digital camera: Sony DSC F828.*

4. Recording and modeling ‘Las Caldas’ and ‘Peña de Candamo’ caves through laserscanning

During the last years, the need of recording and modeling of subterranean places has increased due to the emergence of laser scanner, providing metric and accurate products which can be used in a wide avenue of applications. Laser-based surveying has been used to great effect in some high profile cave sites [3, 11], but the methodology and equipment used is rarely described in detail, and is certainly not an affordable option for most archaeological projects. To overcome these problems and to provide a straightforward and affordable tool for archaeologists, the utility of an automated laser scanner was evaluated through the survey of two complex and irregular palaeolithic caves. The next scheme (Figure 7) tries to illustrate the hybrid methodology that we have developed and put in practice with the aim of recording and modeling both paleolithic caves.

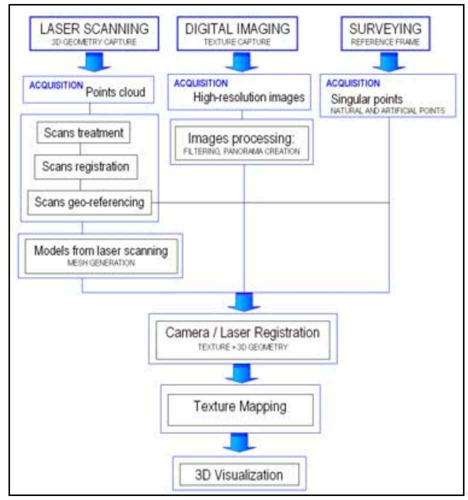


Figure 7: *Laserscanning methodology at caves.*

4.1. Planning

Several are the aspects that need to be discussed and solved in a planning step:

<u>Client requirements</u>. In our case a fundamental question needed to be asked: “*what does the prehistorian require or what are the results demanded in the project?”*. This is particularly useful for recording archaeological details where the requirements are often quite foreign to the standard types of mapping undertaken by surveyors or photogrammetrists. Thus, sometime we could spend time, energy and money to produce a 3D model and fly-through animation when all that the client required is a sketch to indicate approximate shape and size in 2D only.

<u>Project goals</u>. It constitutes together with client requirements the two main factors, so determine the rest of aspects in the planning step including the own methodology.

The goals in both caves were the same. On the one hand, a metric 3D model was necessary which could recreate interactively and with high accuracy the paleolithic caves. In this sense, a global cave model was reconstructed which incorporated detailed scans corresponding to paleolithic engravings. In order to appreciate the quality of these engravings, high resolution images were registered with laser dataset providing a textured polygonal model. On the other hand, the second goal was to integrate the metric information provided by the laser model with the different datasets belong to different archaeological campaigns excavated in the 70's, allowing to develop a digital archiving of both caves.

Object: features and limitations. Its morphology and physiognomy, level of difficult, materials, geometries, possible occlusions, etc.

The recording and modeling of subterranean places such as caves are limited by the adverse and different conditions that can be founded under ground: from physical features i.e. a difficult access, reduced illumination and high humidity, to technical features that have to be solved with an adequate methodology and specific instruments.

Environment: features and limitations. The presence of vegetation, a difficult access and the presence of tourists are also aspects to take into account.

Technique and instrumental selection. In our case, a terrestrial laser scanner combined with a high resolution digital camera constituted the main instrumental support.

In this sense, the following aspects had to be considered:

Number of stations and their position. A balance between the number of stations and their coverage should be achieved, avoiding the presence of holes and occlusions and allowing the presence of an overlap between scans around 10% at least.

Scan resolution. Obviously this aspect depends on the goals and results demanded on the project, so a balance between accuracy and economical cost should provided the grid resolution required. Furthermore, scan resolution is a factor which depends directly on object's distance.

Reference system. Usually, tasks performed by laser scanner must be geo-referenced in a local reference system based on surveying measurements or an archaeological grid. In our case, several artificial targets (planar targets and spheres) were placed at caves with a double purpose: register all scans in a common reference system and geo-reference the laser model into the archaeological reference system, allowing to integrate both dataset (Figure 8).

Figure 8: *Artificial targets and spheres used for registering scans and for defining the archaeological reference system.*

4.2. Data collection

The bad illumination conditions together with the complex geometry and the resolution required, had as consequence that laser scanner combined with a high resolution camera were the perfect instruments for the data acquisition.

Three different types of scans were acquired in the data collection step:

Global scans set up with an average grid resolution of 20 mm at 10 meters of distance, with the aim of recording the whole cave. A total of six stations were required at 'Las Caldas' cave, while one station was only required at 'Peña de Candamo' cave. In order to guarantee good quality in the scans registration an overlap around 25% was preserved between adjacent scans.

Detailed scans set up with an average grid resolution of 2mm at 10 meters of distance, with the aim of recording with a high accuracy the paleolithic engravings of several vertical walls. Two detailed scans were acquired in both caves: one for recording the petroglyphs presented in 'Las Caldas' cave and the other for recording the pictographs presented in 'El Muro de los Grabados' at 'Peña de Candamo' cave.

Singular scans based on individual surveying measurements with laser scanner. 6 artificial targets and 3 natural points (specially used by the prehistorian) measurements were needed to 'tie' the archeological dataset to the points cloud defined by the laser scanner at 'Las Caldas' and 'Peña de Candamo' caves respectively.

High resolution images acquisition can be performed in an independent way with relation to laser scanning. Nevertheless, in order to registering both dataset correctly, the separation between both sensors should not be very big. Two different types of high resolution images were acquired:

Independent images, used to map textures over detailed scans.

Panoramic images, used to provide a 360-degree panorama background at paleolithic caves and to complement global scans mapping textures over the global laser model.

4.3. Data processing

It has to do with the most expensive and time-consuming step in the laser scanning pipeline. In fact, it usually supposes an increase about three times more with relation to data collection. Nevertheless, it will be again the goals and results which will demand the type of data processing.

In our case, the following tasks were performed:

Scans registration. Six different scans were registered in a common reference system supported by artificial targets and spheres. An overlap about 25% was maintained to guarantee good quality in the iterative registration process based on the ICP (Iterative Closest Point) algorithm [1]. An averaged error of 3-5 mm was obtained in the registration process. Figure 9 shows the registration of two adjacent scans at 'Las Caldas' cave.

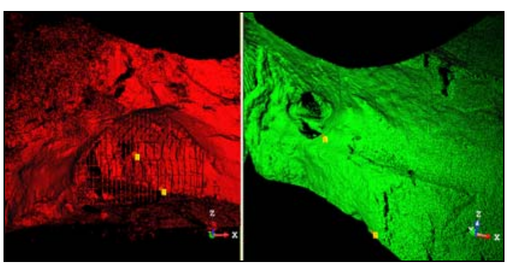


Figure 9: *Scans registration at 'Las Caldas' cave.*

Segmentation and filtering. All those points or elements unnecessary were deleted. Different automatic filters combined with manual segmentations were applied to obtain a depurated laser model. In particular, those unnecessary points situated out of the main walls were deleted automatically using maximum and minimum distance thresholds, while those unnecessary points corresponding to rock elements were discarded manually.

Mapping textures. Since the majority of laser scanners provide poor color information an external camera is necessary to register high resolution images with relation to laser model. This registration process requires time and manual interaction to achieve good results. Individual and panoramic high resolution images were registered with relation to laser models using a minimum of 8 homologous points. Particularly, a least square adjustment based on collinearity condition is applied using pixel (high-resolution image) and terrain (point cloud) coordinates as input data. Terrain coordinates are obtained from laser scanner file which relations every pixel of range image with its 3D point projection.

This step constitutes the most difficult one, since we are trying to link two different sensors which exhibit different features. Thus, it would be easier if both sensors would be closed each other. As a result, a projection model was computed which allowed us to connect the 2D image points with the 3D laser points.

Geo-referencing laser model. A reference system inherited from the archaeological dataset was applied to the laser model, in order to put in the same framework the measurements and drawings provided by the prehistorian together with the 3D model. To this end, an identification of control points (special targets) surveyed with the total station and acquired with the laser scanner and the digital camera is performed manually. A spatial 3D Helmert transform based on least squares is used to align all dataset in this common framework, obtaining new rotation, scaling and translation parameters. The principle of 3D Helmert is based on the transformation equations between two different coordinate systems.

4.4. Derivate products

Up to now the obtaining of final products by laser scanning is something that requires time and patience yet. However, several final products such as: cross-maps, sections, triangular meshes, surveying measurements and obviously the metric support are obtained immediately.

In our case, the following derivate products were obtained:

A global metric 3D model with an average accuracy of 6 mm, which allow to the prehistorian the extraction surveying measurements interactively, i.e. distances, angles, surfaces and volumes (Figure 10).

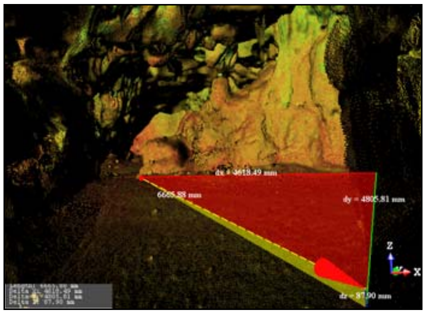


Figure 10: *Global metric laser model, 'Las Caldas'.*

Several cross-maps and transversal sections in a vectorial format that show the shape and profiles of the caves, as well as a plan of the floor which incorporates the archaeological grid and a reference axis (Figure 11).

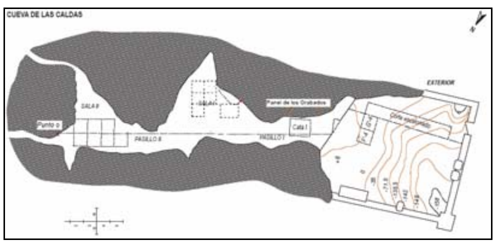
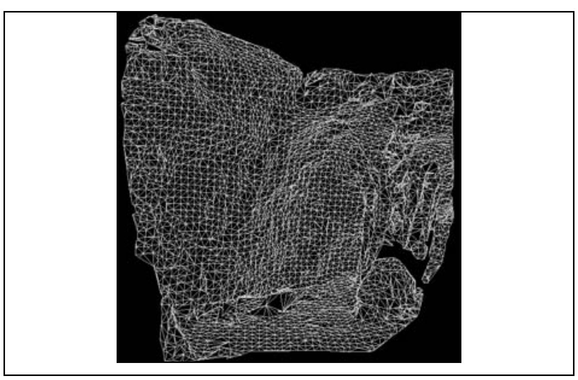


Figure 11: *Floor plan extracted from laser scanner at 'Las Caldas' cave.*

A 3D textured model based on a triangular mesh. Figure 13 shows the triangular mesh, relief shading and then the addition of image texture at 'Peña de Candamo' cave (Figure 12).



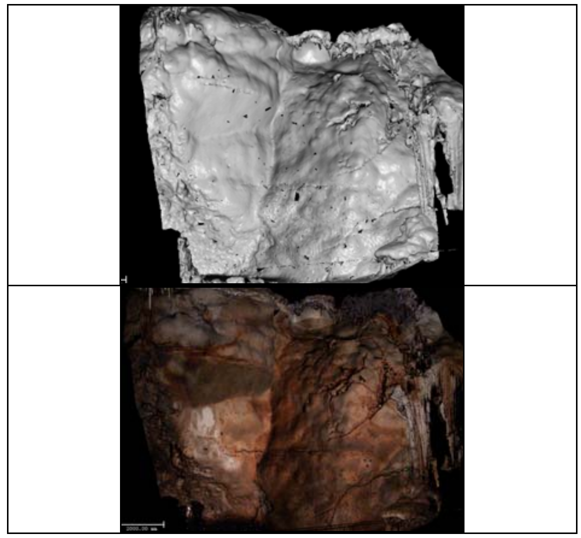


Figure 12: *3D model generated with laser scanner at 'Peña de Candamo' cave.*

Color orthophotographs of detailed scans such as: 'El Muro de los Grabados' and several engravings at 'Las Caldas' cave. The real significance of the orthophoto is the removal of relief and tilt distortions providing an image with the qualities of a map. For example, horizontal distances between features can be directly scaled from the orthophoto.

A digital archiving of both caves based on the integration of laser model and relevant prehistoric data, i.e. historic information, dating and prehistoric artefacts (petroglyphs or pictographs).

Virtual flies-through that combine different modes of visualization dynamically: from the intensity points cloud and wireframe models to the textured models which superimpose cross-maps and transversal sections.

A total of two months were required to accomplish the recording and modeling at 'Las Caldas' and Peña de Candamo' caves through laser scanning.

5. Conclusions and future perspectives

In this paper, the role of laser scanning combined with high resolution image registration for the digital recording and modeling of two paleolithic caves has been presented. The final results provided by laser scanning technology have been well accepted by prehistorians and archaeologists professionals, since they usually obtain metric measurements based only on classical approaches not very accurate and consuming a lot of time. Even the direct points cloud provided by laser scanner have lived up to their expectations, since they use points representations to draw complex geometries sometime.

Therefore, there can no doubt that laser scanners will be a 'tool of the future'. Their potential is immense; however, from our professional photogrammetric background the extraction of final results have required time and patience. The presence of complex and irregular geometries, event really common in Archaeology, have provided that plans or vectorial documents required manual interaction, being impossible to extract scaled and metric engravings from laser models automatically. Furthermore, the integration of geometry and high resolution textures was not completely satisfactory since radiometric information is limited by the geometric resolution of laser scanner, so only high resolution information was applied to measured points. The easiest solution passed through applying the mapping texture over the mesh model. Nevertheless, due to the inaccurate detection of edges and corners from laser scanner data, several parts of the mesh were not correctly mapped.

In a near future, as a part of the same Research Project and with the aim of solving some limitations remarked above, we could develop an algorithm that would allow filling the holes of laser points cloud interpolating points with colors. Furthermore, in a virtual reality context, we hope to recreate and developed an augmented reality platform which combines the reality support provide by the laser scanner together with virtual recreations based on the dataset obtained through archaeological campaigns and the prehistoric studies performed.

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