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Pierre Grussenmeyer[1], Albane Burens[2], Emmanuel Moisan[1], Samuel Guillemin[1], Laurent Carozza[2], Raphaëlle Bourrillon[3], Stéphane Petrognani[4]

[1]UMR 7005 LSIIT-TRIO, INSA de Strasbourg, 24 Boulevard de la Victoire, 67084 Strasbourg Cedex, France
[2]UMR 5602 GEODE, Université Toulouse-le-Mirail, Maison de la Recherche, 5 allées A. Machado, 31058 Toulouse Cedex 1, France
[3]UMR 5608 TRACES, Université Toulouse-le-Mirail, Maison de la Recherche, 5 allées A. Machado, 31058 Toulouse Cedex 1, France
[4]UMR 7041 ArScAn, Maison R. Ginouvès, 21 allée de l’Université, 92023 Nanterre, France

Abstract. The archaeological cave « Les Fraux » (Saint-Martin-de-Fressengeas, Dordogne) forms a great network of galleries, characterized by the exceptional richness of its archaeological Bronze Age remains such as domestic fireplaces, ceramic and metal deposits, fingerings incised in the clayey-walls. The cave has been closed according to the collapse of its entrance, at the end of the Bronze Age. The study in progress takes place in a new kind of tool founded by the Institute of Ecology and Environment (INEE): sites dedicated to the study of global ecology. In that framework, we develop new methods of data acquiring based on 3D contact-free measurement techniques, according to an interdisciplinary way. A partnership among archaeologists and surveyors from INSA allow the 3D recording and modeling of the global volume cave. In the same time, we implement the high resolution recording of parietal representations (engravings and fingerings). The aim of this paper is focusing on the complementarity of data which are produced by the different scales of 3D recording used in the cave. Another purpose is to issue a statement of the different 3D technologies tested in “Les Fraux”. Finally, we propose to start a discussion about the way we try to produce an accurate 3D documentation and adapted to the researchers needs.

Keywords: Documentation, Terrestrial Laser Scanner (TLS), Photogrammetry, Close range, ScanArm, High Resolution, PDF-3D, Archaeology, Cave, Bronze Age, Dordogne-France.

1 Introduction

There are more and more 3D recording projects in underground environments related to archaeology. Such projects are often the opportunity for scientists from different fields as social sciences, environmental sciences and engineering sciences to meet. The resulting works are a major challenge both in the processing, the management and the publication of the data acquired as well as for the development of simulation tools. The aim of this paper is to present experiences and a selection of results gained during the recording of an underground anthropic network from the Bronze Age, namely the archaeological cave “les Fraux” (Saint-Martin-de-Fressengeas, Dordogne, France). We propose to explain the recording methodology applied on this site since 2008, as part of an interdisciplinary approach, and explain the methodological key issues faced.

2 Context of the research

The Bronze Age cave « Les Fraux », discovered in 1989 is a complex underground network of narrow horizontal galleries of more than 1km long [1]. Human occupied this underground paleo-ecosystem during the Bronze Age (end of Middle Bronze, late Bronze Age: 1450-1150 BC). There are several valuable remains in this exceptional field of investigation: signs of domestic development, deposits of ceramic and metallic furniture, parietal expressions (patterns and fingered depictions carved into the soft clay walls and ceiling of the cave). The nice preservation of archaeological soils as well as the structures and decorated walls is to be linked with the collapse of the entrance porch of the cave at the end of the Bronze Age [1]. The remarkable state of the cave is an invaluable asset to the study of interactions of the Bronze Age societies with their environment. These interactions are studied by analyzing the alternating phases made of strong anthropic constraints and steps back to natural functioning. The study of this network is part of a planned multi-year archaeological excavation led by L. Carozza and funded by the regional office of Aquitaine of the French Ministry of Culture and Communication. The French National Research Council is also supporting this project labeled as a research site in Global Ecology (called SEEG) from 2011 to 2014 under the coordination of A. Burens. The aim of the SEEG is to consider the site as a laboratory where new methods of data acquisition can be tested and which operate resolutely interdisciplinary approaches. Our aim is the interpretation of archaeological data for the development of studies combining time and space (paleo-environment, archaeometry, geochemistry, laser scanning, 3D modeling ...), in an approach where all stages of the research are integrated, from data acquisition, implementation of protocols of observations, experimentation, or simulation until restitution.

3 Methodology

For the archaeologists, the documentation and recording work (started in 2008) shall contribute to the accurate indexing and georeferencing of the whole set of surveys and images of the remains and collections as well as structural elements and relief drawings acquired in the different parts of the cave. Most of the projects dedicated to the recording of caves combine terrestrial laser scanning and close range photogrammetry [2], [3]. These techniques not only yield to drawings such as sections and elevations, but also to photo-realistic perspective views and visual navigation worlds in 3D environments [2]. There are different approaches for recording from terrestrial image data [4]. Other methods can enhance activity recognition in environments with occlusions, noise and illumination changes by employing neural network readjustment [5]. As our project is based on the idea of an integrated and interdisciplinary research, it was crucial to process a geometric model of the cave as a common research tool, usable by all partners of the scientific team. Thus, we set out to implement a 3D topographic survey of the entire volume of the cavity (Figure 1) ensuring, in addition to the visualization of the network, the georeferencing of various types of information (structural, archaeological, archaeometry, records of decorated walls...) recorded in the various galleries of the cave. Furthermore, we wanted to test innovative and experimental approaches combining photogrammetry and terrestrial laser scanning, including for parietal works. Therefore a public partnership between archaeologists and surveyors of INSA Strasbourg (Photogrammetry and Geomatics Group) has been established in 2008, supported by a scientific partnership with the FARO Company. The cave is linked to the above terrain thanks to surveying techniques (total station underground and GPS measurements in the field), allowing the aggregation of information and its accurate georeferencing in the French Geodetic Reference System.

3.1 Recording of the global network of galleries by terrestrial laser scanning

The terrestrial laser scanning (TLS) data acquisition required to process the overall 3D model of the cavity has been performed using a FARO Photon 120 scanner and more recently a FARO Focus 3D one. The expected accuracy of both scanners is about 2 mm at 25 m. Spheres and targets have been used for the registration of the point clouds and the geo-referencing (Figure 2). The acquisition of point clouds occurs through repetition in space of scanning stations along the galleries. An overlapping area between two stations is routinely provided. For the details of the recording methodology by TLS, the reader can refer to [6] and [7].

One TLS station requires about 7mn for 40 Million points. The distance between the stations varies between 2m to 5m depending on the complexity of the cave sections. More than 300m of galleries have been recorded at this stage representing approx. 80 stations and 20 days of recording in the cave. If we consider a point density of 1pt/mm, each meter provides approximately 10 Mo points. The postprocessing work and the merging and georeferencing of the point clouds have been thoroughly processed by B. Cazalet, V. Léglise, E. Moisan (Master students from INSA Strasbourg under the supervision of Pierre Grussenmeyer). Handling data from multiple stations requires a resampling of the point clouds. The point clouds can then be saved in ASCII format and afterwards imported and merged into a uniform point cloud. Georeferencing of the individual point clouds avoid a time consuming consolidation step. Raw data are archived on the backup server of the Photogrammetry and Geomatics Group before the post-processing works.

3.2 Texturing the point clouds: towards a photorealistic rendering

The processing of very high definition images quickly appeared crucial to the study of rock art panels in the cave [8], [9]. This requirement led us to work on a different scale from that used for the volume of the network of galleries. The team has tested various alternatives to the problem of acquisition and correlation of very high resolution digital photographs of the clay panels with the 3D volumetric model of the cave. We made a first test of simultaneous acquisition of the 3D model coupled to the digital shots and automatically georeferenced by the Trimble VX equipped with an internal camera. Unfortunately this camera is limited to 3,2 Mpixels and does not fit with our needs. This experience has been followed by the recording of point clouds with a Faro Photon 120 laser scanner equipped with a Nikon camera color kit. We encountered again a methodological problem. The modification of the camera settings was impossible during the automated recording process of the images. Thus we were unable to process automatically the produced photographs. In 2010, we continued our work by undertaking a series of very high resolution digital images of a large clay panel in the sector 13. This work was carried out using a Canon EOS 5D equipped with 85mm and 20 mm lenses and mounted on a panoramic pan head, allowing the realization of nice and accurate panoramas views (Figure 3) with a pixel size in the object below 0,5 mm. The camera tripods were placed at two different locations in front of the clay panel. The exterior orientations of the different photographs of the panoramas were processed in a photogrammetric bundle and imported in the point cloud processing software in order to get a very accurate colored point cloud and meshed model.

In parallel, we have experienced in 2010 and for the first time in underground and archaeological context, the latest generation of a Faro ScanArm V3 (19 200 points/sec and 0,035mm accuracy). The exceptional quality of

the acquisition of this point cloud is due to the accuracy of the FARO fusion arm and the laser V3 head maintained by the operator at a few centimeters of the object during the time consuming recording (Figure 4). The same area is scanned at several times and different angles to overcome the problem of incidence of the laser in order to fill the holes of the model. The georeferencing of this very accurate point clouds is obtained after registration with the global 3D model of the cave. The use of this generation of scanner is undoubtedly a methodological advance.
This new equipment, providing sub-millimeter resolution, has enabled the team to carry out experimental work on identifying the various techniques used and tools used to achieve the decorated panels (Figure 5). The study is conducted on several panels of the cavity and their experimental duplicates (made of clay materials using a wide range of tools: flint, bone, bronze and copper spikes, dry wood, freshly cut branches, fingertips, etc.).

The objective is to discriminate different techniques as fingering, engraving, or etching from the traceology. The flexibility of the ScanArm was able to record the bottom of the prints and the finest carvings, including oblique ones. The data is currently under study. We want to compare archaeological models and experimental duplicates to compare sections drawn in order to discriminate the morphology or the type of the used tools.

3.3 PDF-3D format as exchange format for the research partners

The need to facilitate the exchange and dissemination of data within the team led us to export the global 3D model of the cave, resampled at 1 pt/cm, in PDF 3D (Figure 6). Thus, the user is able to handle the 3D model in the Acrobat Reader (8.0 or higher) installed on his computer. This format allows as well some measuring functions and toolkits (distances, sections, etc.) and visualization options such as wireframe, shaded, solid, vertices, etc. Such an overall model is not aimed to represent details, but to show the geometry of the cave. The quantity and definition of data acquired by laser scanning permitted a higher density (1 point/mm). Thus, each partner of the team can have a file for viewing and easily handling the data without any special software.

4 Conclusions

The documentation project began in 2008 and several challenges have been faced, mainly (i) integration of heterogeneous data acquired at different scales and resolutions in a global 3D model and (ii) coloring the point clouds and texturing the 3D models by mapping images acquired at very high resolution [11]. Beyond the completion of the 3D scanning of the volume of the cave and the generalization of recording high definition 3D archaeological clay panels of the cave with the FARO ScanArm, our projects in the short and medium term are focused on:

- Finalization of the experimental approach of traceology applied on parietal art;
- Further research on the texturing of high resolution 3D models from calibrated cameras and new scanners;
- Optimal solution to the problem of mapping of high resolution digital photographs on the 3D model;
- Request of parietal art specialists to have georeferenced 3D photomodels of the clay panels in order to be able to compute orthophotos used during their fieldwork;
- Solutions for automatic image orientation processing and dense colored point cloud generation;
- Integration of the overall volume of the cave in a digital terrain model to better understand the evolution of Karst topography.

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