XXVI VALCAMONICA SYMPOSIUM 2015

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PROSPECTS FOR THE PREHISTORIC ART RESEARCH
50 years since the founding of Centro Camuno

PROSPETTIVE SULLA RICERCA DELL'ARTE PREISTORICA
a 50 anni dalla fondazione del Centro Camuno

Centro Camuno
di Studi Preistorici

Proceedings

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Valcamonica 3.0: a new dimension in rock art recording. From tracing to Structure from Motion and Post-processing

Paolo Medici * and Giulia Rossi *

Summary

The goal of this work is to develop a methodology aimed to integrate the not-digital documentation (tracings, data sheets and other) with the digital documentation (digital photography, GIS, 3D documentation, databases). The main purpose of this integrated methodology is to produce a documentation which is accessible to the researchers and which is not already an interpretation, giving to the scholars the possibility to interpret a neutral data. Even if the tracings have reached a high level of accuracy and objectivity, they are anyway an interpretation of the operator, mainly when there are superimpositions, very tiny engravings (filiformi), or complex scenes; in these cases the possibility that everyone has access to the same objective data is fundamental for the research. Furthermore the new technologies, in particular the 3D, can be useful to protect and to value the heritage, for example, an exact 3D model can be created in a museum to show a rock no more accessible or covered for safeguard purposes. The post-processing work on 3D models can enhance the visualisation of engravings almost erased, superimposed figures, and others.

Riassunto

L'obiettivo principale di questo lavoro è quello di sviluppare una metodologia finalizzata a integrare la documentazione non-digitale (rilievi a contatto, schede tecniche, frottage etc.) con la documentazione digitale (fotografia digitale, GIS, restituzione 3D, basi di dati). Tale metodologia integrata è finalizzata a ottenere una documentazione scevra da ogni superfetazione o interpretazione e che sia al contempo facilmente accessibile dalla comunità scientifica, dando, in questo modo agli studiosi la possibilità di confrontarsi in prima persona con un dato, per così dire, neutro. Sebbene la tecnica del rilievo a contatto abbia raggiunto un elevato livello di precisione e obiettività, infatti, la documentazione ottenuta attraverso questa metodologia resta ancora sottoposta, pur se in piccola parte, alla soggettività e all'interpretazione dell'operatore; questo, in particolare, risulta evidente nel caso di sovrapposizioni fra più immagini o di incisioni ridotte nelle dimensioni. I trattamenti di post-processing sui modelli 3D possono, infatti, migliorare la visualizzazione di incisioni abrase o scarsamente percepibili e possono rappresentare un valido aiuto nei casi di sovrapposizioni complesse. Le nuove tecnologie, inoltre, e in particolare il 3D, possono fornire un apporto decisivo nella tutela e nella valorizzazione dei beni culturali attraverso, ad esempio, la restituzione 3D di oggetti non più accessibili a studiosi e visitatori.

In the last 30 years the archaeological world has been deeply modified, in particular in the field of the acquisition of the data and the documentation. This change happened thanks to the introduction of the computer science technologies, it has been a slow and gradual process, but it has been continuous and irreversible. The use of electronic databases, total station, GIS, and other is fundamental and nowadays essential for the documentation in every archaeological site[1].

In the same way, also in the field of the rock art research this process is already on going since several years, with many experiments to apply these new technologies given by the computer science to the rock art studies.

Some of these technologies havebeen involved in the normal process of the studies in most of the rock art institutes, such as electronic databases, geo-localization of the rocks and others, but other techniques have seen an episodic use without have the force or have shown the entire potential to become of common use in the documentation of rock art. In particular the 3D reconstruction has seen a long and not happy history of experimentation. Indeed in the past it has been tried several times to use laser scanners to record in three dimensions the engravings[2], but for several reasons (encumbrance of the device, costs, necessary conditions to operate and others) the experiments always failed to impress the archaeologists, denying the access to this type of documentation among the digital technologies which help the traditional recording of the rock art.

The goal of this work is to develop a methodology aimed to integrate the not-digital documentation (tracings, data sheets and other) with the digital documentation[3] (digital photography, GIS, 3D documentation, databases); in particular with the creation of models of the rock thanks to the elaboration of three-dimensional data. The second goal is to produce a documentation which is accessible to the researchers and which is not

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1 D'Andrea, Barbarino 2002; Fortunati *et al*. 2014.

2 D'Andrea, Iannone, Saffiotti 2009; D'Andrea 2011; Hermon, Pilides, Amico, D'Andrea, Iannone, Chamberlain 2013.

3 Bisogno 1980.

already an interpretation, giving to the scholars the possibility to deal with a neutral data.

Considering an aspect more linked to the conservation and valorisation of the cultural heritage, since many years, the computer science technologies have shown a valid and important support to these purposes[4]. Indeed these innovations can contribute to the safeguard of the artistic and archaeological objects and sites, representing a fundamental tool in the conservation of the cultural heritage. Furthermore, the introduction of the computer science technologies has modified the modern approach to the museums itineraries, aiming towards the use of device which can involve the visitors with new experiences of knowledge, but also of entertainment. The concept is clearly stated by Calandra: "La presenza sul mercato di nuove tecnologie favorisce l'intensificarsi di esperienze all'interno di scenari espositivi e museali sempre più significative, arricchendo il patrimonio di ogni percorso culturale e portandolo verso quel concetto di *infotainment* (informazione - intrattenimento) in grado di avvicinare le diverse tematiche e target di pubblico sempre più diversificati"[5].

In the same way, we believe that also in the field of rock art it is fundamental introducing new tools, in particular the creation of 3D models, which can make easier the understanding and fruition of the engraved surfaces. With these three-dimensional reconstruction the visitors, as well as the student, can interact with the archaeological object through an interactive interface which allow to the user to interact dynamically with the model before to visit the real site.

The 3D reconstruction is the process (automatic or assisted) to generate a model which is a precise copy of a real object. These three-dimensional reconstructions need of a device in order to acquire the shapes and measures of the object to recreate. The information gathered by the device will be processed with specific software which generate the 3D model, the precision and accuracy of this model will depend on the type of capturing device and the software used. There are several methods to obtain information for reconstructing a real object in 3D: laser scanners, resuming the shape from the shading, stereoscopic view, structure from motion and many others. We have evaluated different parameters such as accuracy or the reconstruction, equipment required, usability, transportation ease, costs of hardware and software and others minors parameters.

The result of the analysis has brought out that the structure from motion (SfM) matches most of the required features:

- accuracy: SfM can reach an accuracy of 0,1 mm, an accuracy below the millimetre (even lesser than 0,1 mm) is required to reconstruct the filiform engravings. Even other methodologies can reach this accuracy, but in the case of the SfM it is reached with a low price and a lighter equipment.
- equipment required: the SfM methodology needs only of a DSLR camera. We have reached the aimed precision with a Nikon D3100. A better camera gives back a better accuracy. This cameras are affordable, furthermore most of the archaeologists have a DSLR for the usual photos during the fieldwork.
- usability: in this category we have gathered both the dimension of the equipment itself (such as a laser scanner) and the facility in the use of it. The use of big instrument can be a problem, in particular if the area object of recording is not flat and the equipment used is heavy and need to be placed with certain inclination or other. On the other hand, some methodologies require shadow or complete darkness, so in particular environments it is almost impossible to obtain that, because of the position of the typology of object to record, such as a rock with particular shapes. Others require long time to acquire the data or force the operator to stay in uncomfortable positions for many minutes. Instead, the SfM techniques is fast and require only to take 10/20 photos of the objects (or for any portion of that object if it is big). It can be used in any condition of light, the only inconvenient of this methodology is that the object to record need to be static and cannot have moving shadows on it. This problem can be solved quite easily taking the photos with the light before the rise of the sun.
- transportation ease: as already mentioned before some equipment which are heavy and big are not easy to transport, especially if the locations to record are in mountains or require to be reach by foot with long walks. The SfM require only of a DSLR camera which usually weighs less than 1 kg and it does not require neither a tripod nor flashes or other accessories.
- costs: the costs involved in the production of 3D models with the SdM techniques are the one of the DSLR camera, which is around 400/500 € for a base camera (which is enough to obtain a dence cloud of millions of points) or 1000€ for a better camera. Of course an advantage is that the equipment required for this methodology, the photo-camera, can be also used for all the other purposes of a camera, so it is not an instrument with only one use. The software to process the data are both open source and with license to pay (most of the software which require a payment license have also an education licenses for research institutes, which are far more cheap). In most of the cases the open source software is enough to obtain an high quality point cloud or mash, the software with a license to pay usually have more features, such as the possibility to place markers to work in cooperation with a total station, or the possibility to export the model in different formats and other.

The Structure from motion technique is part of the "range imaging technique", which allow to obtain a 3D model from a sequence of 2D images. The human vision usually acquire 3D information thanks to the stereoscopic vision: the image of any object is projected from different views on both retinas, and their

4 Bonacini 2011.
5 Calandra 2011, p. 36.

displacement can be used to triangulate the position of the object. We can retrieve also depth information using only one eye, in particular the human eye can obtain depth information from the motion, and the SfM technique starts from this principle. SfM is based on the process of finding three-dimensional structure of an object analysing local motion signals over time[6] (Fig. 1). In particular it is assumed that the objects in the scene are static and the relative displacement depends only on their depth. Taking a set of photographs (or video) from different positions it is possible have the same point of a scene taken from different orientation, the algorithm will process that information giving back the position of that point in relation of the next points, creating a point cloud with each point that is placed in a three dimensional space generating a 3D model of the surface recorded[7] (Fig. 2).
This process is converted in a simple action on the field, in fact the SfM methodology consist only in taking photos with a camera (for a good result a DSLR) without the use of any support as tripod or other, just free hand photos, and without the use of a calibration or a photogrammetric camera. The only important thing is to take the photos of the area or of the interested object from different point of views and direction. There are two main methods to take the photos: the parallel photosets, that it is similar to aerial photography flight lines, are perfectly adequate for SfM if each photo overlaps the last by at least 60% to optimize the overlap and parallax. Convergent photos, where the photos are all focused on a central point in the scene, have produced some of the best models. The convergent geometry maximizes both overlap and parallax. For larger areas parallel photos are probably the most efficient and for smaller areas or single objects convergent photos produce the best results.
An important advantage to use 3D models (also not SfM) is the possibility to enhance the reconstruction with several software and in different ways on the basis of their purposes. In particular for rock art, we have experienced of great utility the open source software MeshLab. This software has many instruments for the post-processing, such as the "Lighting" in which you can manipulate the direction of the light, or the "Shaders", which allow to emphasize the shadows, in particular the tool Radiance Scaling give back excellent results.
One of the main problem related to the elaboration of the 3D data, it is the requirements of large spaces on hard disks or servers to store the data (for example the space taken by all the data of the case of study 1 is close to the 3gb), as well as the possibility to have powerful workstations to work faster. Indeed, the software of 3D elaboration can run also on normal laptop, they do not crash under the weight of the processes, but it takes much longer time. We have estimated that with a laptop (with 4gb of ram 2.2 GHz processor and 512 video card) it takes 15 hours to build a 10 milions dense cloud, on the other hand, with a dedicated workstation (8gb of ram 3,6 GHz processor and 1 gb video card), the reconstruction of a 24 millions points dense cloud has only spent 5 hours.

Case of Studies

Reconstruction of the sect. C of the rock 24 of Foppe di Nadro (fig. 3)
3D reconstruction of an area densely engraved for valorisation and museographic purposes.
The surface is a large panel of 4 x 2 meters, one of the most scenographic and famous of the area of Foppe di Nadro. We have decided to divide the area in 10 squares of around 80x80 cm using markers:

Square 1	13 photos
Square 2	11 photos
Square 3	10 photos
Square 4	14 photos
Square 5	13 photos

Square 6	12 photos
Square 7	13 photos
Square 8	11 photos
Square 9	11 photos
Square 10	10 photos

We have used a NIKON D3100 with a 50mm objective, ISO 100, with a resolution of the photos of 4608x3072 pixels.
The photos taken of the panel have been elaborated with the software Agisoft Photoscanner Professional. For every square on the rock correspond a chunk in Agisoft, so we have created 10 chunks, and for every chunk it has been generated a dense cloud of around 20 millions of points. We have also generated a mesh, but evaluating that the accuracy was not better, despite the quantity of data to process were higher slowing down the computer, we have decided to discard the mesh and use only the dense cloud which presented an accuracy already good for the purposes of this reconstruction.
No post-processing has been elaborated.
The reconstruction of the panel taken in consideration has reached the aims that we hoped, the quality of the 3D model is excellent and using the dense cloud we have obtained already usable reconstruction preserving resources of the computer. The model can be of great use in the right context, for example in a museum for the didactic and for the visitors. The reconstruction allows to see the engravings as it could be almost impossible for visitors and student, giving them the possibility to zoom in and zoom out seeing both the whole scene and the single detail of the figure, all this without the problems of the direction of the light on the engravings or the shadow casted on them. Of course this will not substitute the experience of the direct visit of the rocks, but it could be integrated to enhance the experience of the students and the visitors before or after the visit.

Reconstruction of a scene of the sect B. of the rock 60 of Foppe di Nadro (fig. 4)
During the Recording rock-art Fieldwork 2014 of the Centro Camuno di Studi Preistorici, it has been record-

6 Torres *et al*. 2012; Fortunati *et al*. 2014.
7 Hartley, Zisserman 2003; Sastry, Ma *et al*. 2003.

ed a complex scene on the rock 60 (sect. B) with figures superimposed. Subsequently to this complexity in the recording, it has been decided to reconstruct the scene with the SfM technique in order to see if it could help to comprehend the superimpositions and record rightly the scene. Furthermore, we have decide to recreate a 3D model both without the direct sunlight and at the direct sunlight, in order to verify if there was a difference in the reconstruction and in the accuracy of the engravings.

The surface recorded has a dimension of around 50 x 50 cm, so it was not necessary divide it in more squares. We have taken 14 photos, both when the panel was not at the sunlight and when at the sunlight. We have used a NIKON D3100 with a 50mm objective, ISO 100, with a resolution of the photos of 4608x3072 pixels.

The scene recorded have been processed with Agisoft, the dense cloud generated contained around 24 millions of points. As before, we have also generated a mesh with around 30 millions of triangles, but the surface and the details of the engravings, once zoomed in, were more approximated than the dense cloud, so to reach the same quality was necessary 40+ triangles, generating a model to heavy to handle with the workstation. Once again we have decided to use the dense cloud. Nevertheless, the quality of the model is already excellent and perfect for the aims appointed.

The model generated with Agisoft has been exported in a file .ply to be processed with Meshlab. In the process of enhancement the engravings have been enphatized with the tool Shaders – Radiance scaling, and enabling the "Lit Sphere Radiance Scaling".

The results obtained with the3D reconstruction were excellent, we have been able to see in detail the engravings and zoom in the particular features of each part of the scene; moreover with the enhancement of Meshlab the figures were clearly visible and noticeable one from the other, confirming the tracing already made with the traditional method, which required several days to be accomplished and a nocturnal expedition with oblique light to see more details that were invisible during the normal daylight. This case of study has allowed to show the great help that the SfM can give to the research and how can be integrated with the traditional methods of recording. In future cases of complex panels with superimpositions, it will be possible recreate the scene with the SfM and analyse it in laboratory to have a clearer idea and record a more objective tracing. The process has taken only the time to shoot 10/20 photos on the site, than to elaborate the data with the software: for the elaboration in Agisoft of a 24 mil points dense cloud the software has taken 5 hours, in which the operator is not required to stay at the computer or can work on it on other things.

Reconstruction of filiforms on the rock 24 of Foppe di Nadro (fig. 5 and 6)

The third case taken in consideration is a comparison of two distinct panels on the rock 24, in which are present *filiforms*, engraving made scratching the rock with a lithic or metal tool, the result is a figure visible as a tiny cut in the rock, and it is hard to see also to an expert eye. Often these *filiforms* are super or underimposed to the pecked engravings. We have chosen two panels in which the scratched figure were once under and once over the other engravings, in order to understand if with the SfM techniques it is possible to understand the superimpositions of these *filiforms*. The areas recorded are of small dimensions, so it was not necessary divide the surface in more squares.

In the first scene there is a *filiform* dagger of type "introbio" which is considered under other figures engraved, in the second scene a *filiform* warrior is believed being over another engraved warrior.

Due to the small area of the first area we have taken 10 photos, using a NIKON D3100 with a 50mm objective, ISO 100, with a resolution of the photos of 4608x3072 pixels. In the second scene we have taken 14 shoots of the area.

Both the areas recorded have been processed with Agisoft, the dense clouds generated contained around 24 millions of points each. For the *filiforms* we have learned, thanks to the past experiences, that the mashes would have not been useful for the purposes we would like to reach, so we do not have generated them. The dense clouds generated with Agisoft have been enhanced with Meshlab to emphasize the *filiforms*, using both the artificial light tool (the best result is obtained using a double side lighting) and Shaders – radiance scaling.

The results of the reconstruction and the post-processing work have been of great interest. In fact, looking at the two models, it is clear that in the first case the pecks of the engraving are over the scratch of the *filiform*, so is the peck which cuts the incised line. In the second the reconstruction show a pecked figure which is cut by the scratched line of the *filiform*.

Conclusions

The results, emerged from the evaluation of a techniques as the SfM in relation with the rock art, permit to convalidate the tests that we have presented in this work. In particular, in respect to the laser scanner, this technique is decisively resulted more versatile in the context analysed, mainly thanks to its rapidity in the execution, high accuracy, limited costs and a more manageable device and adaptable. The only real possible difficulty of this method regards the environmental light and the moving shadows, but it can be overcome easily taking the photos during the most favourable hours of the day.

It is our opinion that the creation of 3D models of the engraved surfaces has the accuracy adequate to be considered a valid scientific documentation of the rock art, and it can represent a real and useful integration to the tradition method of the rock art recording, to be implemented during the operations on the field.

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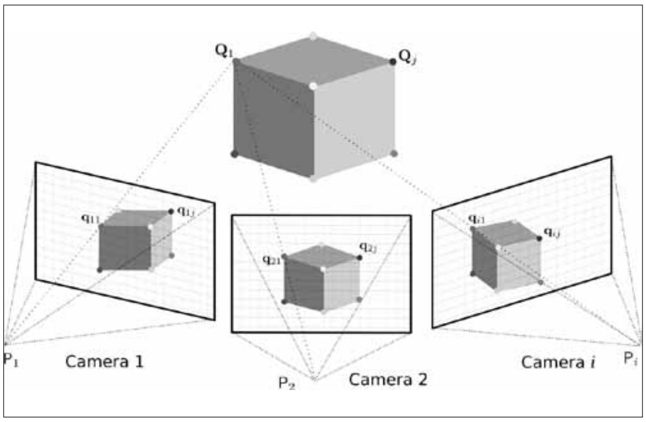

Fig. 1 – Representation of the principle of the SfM techniques (http://michot.julien.free.fr/drupal/?q=content/research).

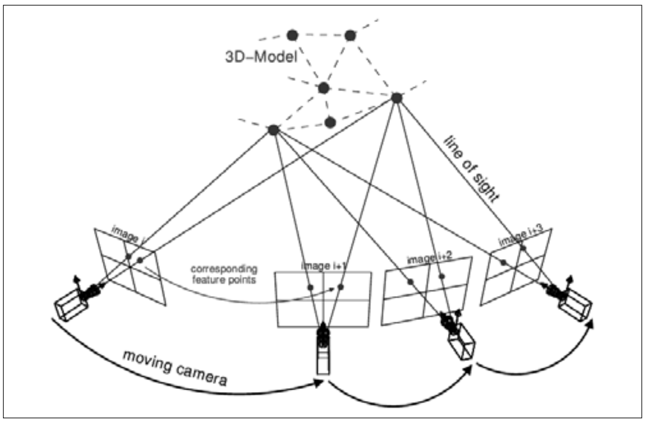

Fig. 2 – The motion of the camera generate the three dimensionality of the model (http://www.theia-sfm.org/sfm.html).

Fig. 3 – A view of the reconstruction of some squares with the positions from where the shoots were taken.

Fig. 4 – The scene on rock 60 of Foppe di Nadro reconstructed with Agisoft.

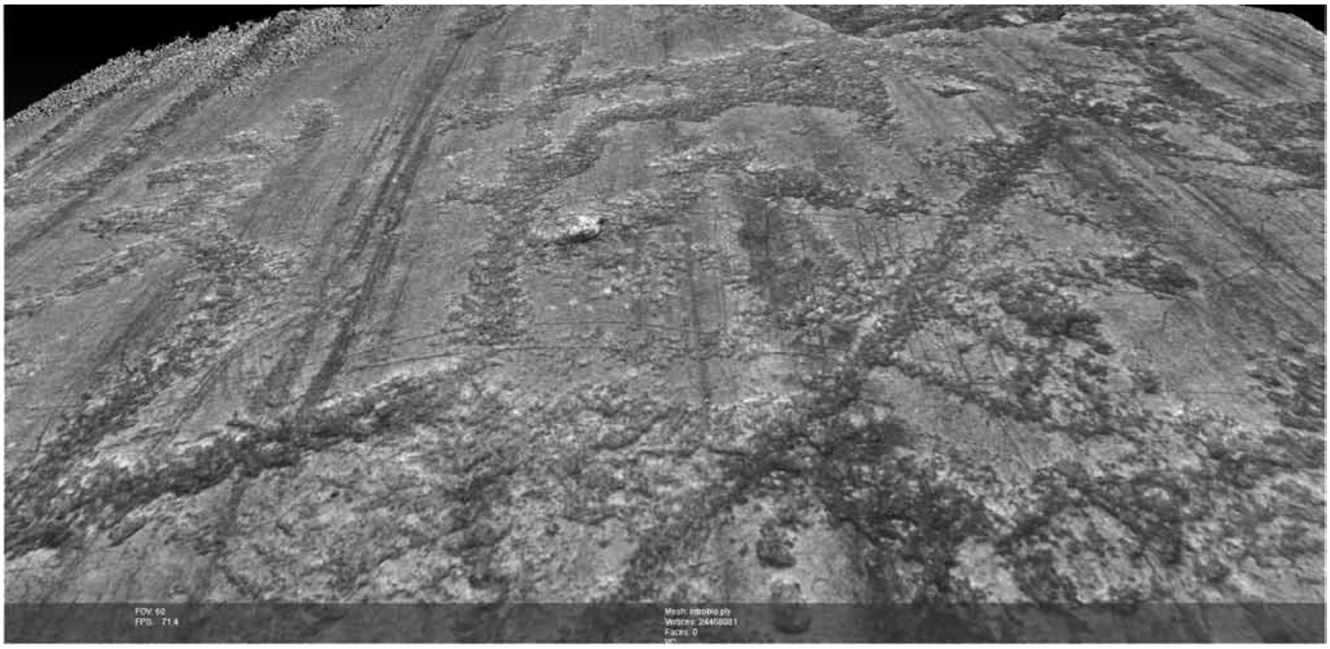

Fig. 5 – A view of the introbio dagger in *filiform* (r. 24 Foppe di Nadro) enhanced with MeshLab.

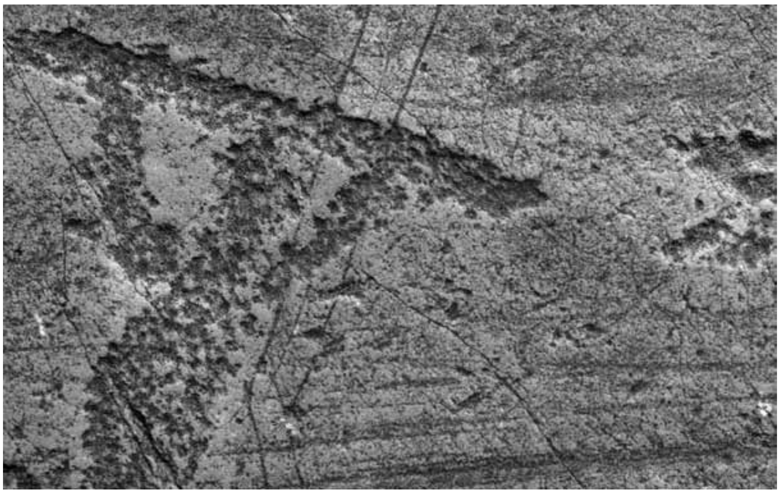

Fig. 6 – A particular of the *filiform* (r. 24 Foppe di Nadro) over the engraved warrior.