

Digital photogrammetry for archaeological artefacts acquisition

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I. INTRODUCTION

Conciliating archaeological heritage preservation and knowledge with technology is one of the challenges of archaeological museums since the last decade. With ICT tools diffusion, curators and public institutions demand new representations of archaeological artefacts. Furthermore, they want to get involved in a collaborative and digital culture to attract a larger public. Nevertheless, digitization is often assumed as a time-consuming and expensive activity without specific and immediate outcomes. Our research group, in last years, deals to change this idea in stakeholders of Digital Cultural Heritage, such as museums director and archaeologist, but also in non-expert users (tourists and public authorities). In fact, also observers report the lack of digital skills and some trivializations in the ICT use [1].

The backbone of the perspective change consists in enabling several applications with the same data set, without dedicated acquisition phases. On this point of view, it is mandatory to achieve a pipeline that is able to perform documentation in case of loss or damage, virtual tourism and museum, education resources, interaction without danger, in deep analysis and so on.

The proposed paper will present several case studies, developed in two-three years period with the aim to point out differences and strong points in each acquisition procedure. The comparison among performed processes, related to the achieved results, constitute a sufficiently large overview for built up a state of art in SfM techniques for the digitization of archaeological findings. In addition, we will discuss the principal issues faced in obtaining compliant resolutions, file size, accuracies, photo-realism, level of detail etc. At the end some considerations will be proposed on the outputs allowed by the 3D models, such as Digital Libraries (DL), web based applications, Virtual reality (VR) interaction, Augmented Reality (AR) app, gaming and conservation-oriented or historical in deep analysis.

II. STATE OF ART AND RELATED WORKS

The digitization process in Architecture and Archaeological Heritage (AAH) domain is currently

based on 3/4D reconstruction, implying point cloud generation. Nowadays technological advances assure several methods for 3D data acquisition. They can be classified in two main groups: image based, that record the electromagnetic energy emitted by the objects to be documented, and range based, that emit electromagnetic energy, e.g. laser beams, infrared light etc., and record its reflection from the object [2].

However, in the last decade photogrammetric algorithms have been automated with the contribution of the computer vision community and hence image based techniques have gained the lost ground in the competition for point cloud generation. In recent years the most robust and accurate acquisition technique for archaeology is certainly Structure from Motion (SfM), applied both for large scale complexes [3, 4] and for statues and pottery [5] [6].

Considering also complex geometry of the objects, particular shapes and material or colour properties, SfM demonstrated robustness, reliability, accuracy and flexibility for the reconstruction of small artefacts. Although there is still a lack of low-cost, open source and automated solutions for collecting mass of archaeological findings, above all considering portability of main solutions [7]. SfM is a particular kind of Digital photogrammetry, a promising method to be improved thanks to the diffusion of robotic survey for Architectural and archaeological Heritage [8].

In our research work we recently have been performed and validated several SfM acquisition [9][10]. These on-field experiences constitute the foundations for giving a state of art of the digital photogrammetry pipeline, allowing all needed outputs.

III. PERFORMED PIPELINE

The standard pipeline of SfM is based on 4 main phases: images acquisition; alignment and dense matching processing; point cloud and mesh creation; modelling, editing, and texturing.

However, the phase of acquisition sometimes requires an amount of time that, depending on the location of the artefact, on the expected scale of the digital model and on the used equipment can be very significant. In our

experiences, as detailed below, we used photo and video camera, terrestrial and aerial acquisition, manual or motorized photographic shootings. In order to obtain HD resolution for small objects, we also tested the Focus Stacking techniques.

IV. CASE STUDIES

The case studies show that similar digitization approaches deal with different goals of work, if performed with minor variations and specific solutions.

A. The Drawing of Mausoleum with garden

The case study here presented concerns a marble slab (lapidary of Ducal Palace in Urbino): the thin engravings represent the map of a mausoleum with garden, one of the few ancient drawings of architecture. The main difficulty of the digitization consists in measuring the microscopic three-dimensional characteristics of the signs. The thin and shallow engravings forced us to a close-up photographic acquisition in order to obtain a GSD (Ground Sample Distance) sufficiently small to describe the details. Then the engravings were extracted through 3D data analysis software, producing a two-dimensional drawing.

We have used an APS-C camera Nikon D90, with a 12.3 megapixel sensor, equipped with the Nikkor 105mm Micro lens. The acquisition distance was set at 1m from the slab, thus obtaining pictures with a footprint of 15 x 22,5 cm of the slab and a GSD equal to 0,052mm. The slab has dimensions of about 90 x 100 cm and this has led to the acquisition, with such settings, of 220 perpendicular photos and 55 oblique. To make the whole acquisition phase easier and more expeditious, we have used a motorized slide mounted on two tripods, on which the camera was installed (Fig. 1). This allowed, in addition to a considerable simplification and speeding up of the acquisition phase, to move from one shot to another in parallel to the slab maintaining constant the distance between the camera and the slab and thus allowing to leave unaltered the focus. All shots were made at ISO 200, time 1/2 sec. and, to avoid diffraction problems caused by too small aperture, we have used f/11 aperture that has allowed to obtain a sufficient depth of field for the perpendicular shots (3,7cm).

Once ended the acquisition phase, which took about three hours, all images taken were processed and subsequently used within the software Agisoft PhotoScan 1.1.6 for the construction of the three-dimensional model. The result is a dense cloud of 314 million points, with an average error of alignment of 0.381 pix (max 0.811, 0.303 min) and an average resolution of 0.052 mm / pix (Fig.2).

The mesh model is the optimal medium for the three-dimensional use of the artwork. Through the 3D navigation of the marble slab we can see with great precision the thin engravings, studying the technique used to make it and identifying the stages of its realisation.



Fig. 1. Photographic acquisition phase with motorized slide mounted on two tripods.

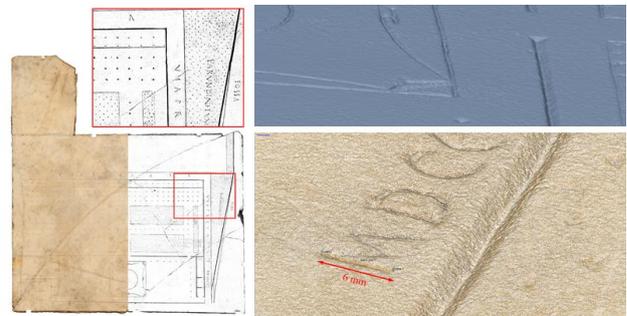


Fig. 2. Comparison between the image and the drawing obtained from point cloud processing (left). Detail of the small engravings on the mesh model (top). Detail of dense point cloud (bottom).

B. The artifacts in the MANaM

In an archaeological museum, where the number of artefacts is very high and their digitization can take long time, the acquisition phase must be optimized in order to reduce the subsequent time of data processing.

So we have developed a quickly and low cost acquisition system that guarantee an excellent photographic quality. This system is suitable for the acquisition of medium-small sized items that can be moved from their natural location and it is composed of a white photographic box, two lamps and a turntable (Fig.3).

The photographic box has the task of spreading the light of the two lamps so not to create sharp shadows on the artefact and to isolate the finding from the space around it.

Once the project of the acquisition is made, the turntable allows to rotate the artefact between two consecutive pictures keeping the camera fixed. The turntable is then equipped with a graduated scale to measure the angle of rotations between pictures, two metric scales useful to orient and scale the final model and a colorchecker



Fig. 3. Instrumentation used for the photographic acquisition

for the white balance and the calibration of the camera colours.

For the survey of small objects it is necessary to increase the focal length and to get close to the artefact with the camera.

There are two main problems in this case: standard lenses has a minimum working distance that does not allow getting too much closer and the depth of field in these conditions is so small that only a small portion of the image appears sharp enough to be used for 3D reconstruction. The first problem can be solved by using a macro lens that have a smaller working distance than standard lenses, while to solve the problem related to the depth of field it is used the focus stacking technique.

The goal of 3D digitization phase is to obtain a very accurate digital *facsimile*, with the propriety of scalability and the possibility to adapt it to different technological solutions, through the optimization of the interaction.

Furthermore, the objects in the exhibition can be very different regarding materials, size, manageability, state of conservation (Fig. 4). We have created the Digital Library (DL) with a good resolution of 3D models, for the dissemination of artefacts, on line and on site, manly for the museum visitors. In this case, we show as the SfM is an adaptive and efficient techniques, sufficiently stressed thanks the National Archaeological Museum of Marche (MANaM) as test-bench.

This kind of 3D allows a large variability of exploitable outputs: 3D printing, stereoscopic view and 3D visualization, etc.

Depending on the geometry and the size, we made different models with different resolutions: for big and unmovable objects we realized a mesh >100K faces; for others, 30K and 70K are the good resolution for light models. An exception is the Frasassi Venus, a calcareous little statue of the Palaeolithic, made by combining CRP and Focus Stacking to obtain a very high quality model. All details about the performed photogrammetric acquisition are available in [9]. For easy and assisted

fruition and dissemination purposes, the better resolution is set in 30K faces, after decimation (Fig. 5).

Chosen the best resolution, particularly important is the texture that have a significant role in the visualization and the exploration of the artefact in DL.



Fig. 4. Digital library of MANaM. Catalogue of artifacts by categories of displacement, materials and size.

While the acquisition of small and movable artefacts is quickly made by the use of the photographic box, for bigger and unmovable artefacts it can not be used so the user has to take pictures moving around the object and data acquisition starts to be slow.

Object	30k	50k	70k	100k	150k	200k	400k	700k	1M
1 Bracciale spiralfornice gallico-etrusco in oro con protome di serpente									
2 Oinochoe in uovo di struzzo di Pitino di San severino									
3 Galletto									
4 Soffitto affrescato									
5 Soffitto con il labirinto									
6 Soffitto stanza con teche circolari									
7 Augusto capite velato									
8 Testa di Agrippina									
9 Pugnale in bronzo di Ripatransone									
10 Testa di Guerriero di numana (Età arcaica) (statua in calcare)									
11 Venere di Fano									
12 Venere di Frasassi									
13 Capitello									
14 Coppa su alto piede a quattro anse									
15 Epigrafe									
16 Bronzo votivo (kouros)									
17 Kylix									
18 Suonatrice di kythara danzante									
19 Pisside attica									
20 Sfinge alata									
21 Statua di togato da via Saffi									

Fig. 5. 3D models for Digital Library. Table with archaeological artefacts and model size: different sizes for different features.

For this reason, we have tested on an unmovable artefact the use of video for the construction of 3D model. The find selected was the *Suonatrice di kythara danzante*, already digitized with photographic technique. The video was recorded with Sony a6300 camera and 4K resolution. Moving slowly around the artefact in just two minutes the acquisition was completed. Once the video is recorded,

we decided to extract one picture every second of video, obtaining in this way 120 pictures. After deleting some pictures we processed all the remaining 100 pictures with the usual SfM pipeline. Considering the lower resolution of the video frame compared to the acquisition made by pictures, and the lower quality of the video due to the impossibility to have picture in RAW format, the goal was to check the metric and qualitative differences between the two models took with picture and video technique. The comparison between the two models is made with the open source software CloudCompare and the result is a mean of 0,01 cm and a standard deviation of 0,4 cm. Considering that the comparison is made on two models with a reduced number of faces to be quickly viewed on the DL, the result is very satisfying, even from a texture quality point of view (Fig. 6).



Fig. 6. Top view of the model and the alignment of the pictures from video in Photoscan (top) and a detail of the texture

C. The Forum sempronii evidences

The Archaeological Museum of Fossombrone is part of regional project DCE (Evolved Cultural District) for the dissemination of archaeological sites along the Via Flaminia in Marche Region.

For this case, the aim of digitization is to show the digital fac-simile of artifacts in their original sites through Augmented Reality application. Obtaining this goal typically involves the data processing phase with model decimation without loss of details and quality.



Fig. 7. Dense point cloud of the mosaic floor from Domus of Europa

Among several objects conserved in the Museo Vernarecci, we choose to collect 3D data about on two findings: the mosaic floor of Europa's Domus and the fresco painting of Exotic animals Domus. Repositioning this kind of evidences in the real context could improve the visitor experience in the archaeological site of Forum Sempronii.

In addition, based on previous collected data on the archaeological park, a 3D model of the area is created with aerial photos to locate into the AR app the correct position of the finds stored in the museum.

The photographic acquisition does not respect the standards of aerial photogrammetry because the purpose of the flight was properly the documentation with video and photo. The flight was carried out in collaboration with the State Forestry Corps that allowed us to fly by helicopter the entire route of the Via Flaminia. At the flight height the archaeological evidences was clearly visible and we could take pictures along a circular trajectory. These pictures were used in the SfM pipeline that has produced an excellent quality of the dense point cloud.

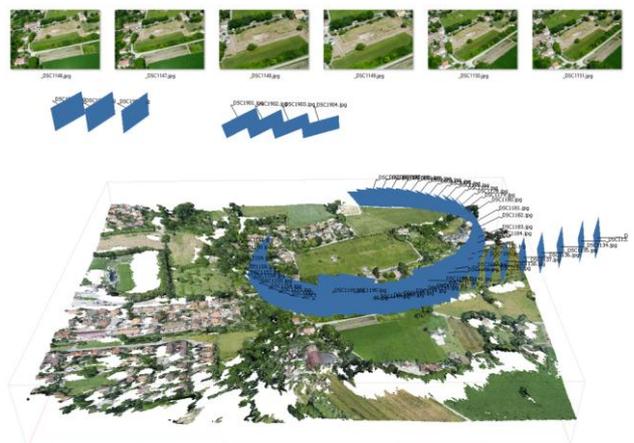


Fig. 8. Aerial photo acquisition (top) realized by helicopter and point cloud (bottom) with camera orientation.

This 3D model, with proper considerations on scale and accuracy, is used as a support grid for inserting the 3D models of the finds located at the museum into the virtual space of the augmented reality application.



Fig. 9. View of dense point cloud of archaeological area.



Fig. 10. APP whit Augmented Reality for the virtual replacement of mosaic in the Domus of Europa, in the archaeological site.

V. CONCLUSION

The performed pipeline allows several outputs and enables to validate deliverables in measurement and dissemination of CH.

Our work promotes the diffusion of the digital data, in particular three-dimensional data, in museum and archaeological context and contributes to the training of new professional profiles among archaeologists and museum workers.

In addition, similar works contribute to a larger sharing of guidelines for different 3D digitisation methods regarding the museum collections. As above mentioned, archaeological objects are very different in terms of shape, size, colour, materials and many objects have mixed material (or mixed surface texture). The non-

exhaustive analysis presented here, mainly consisting in case studies, demonstrated how the same photogrammetric technique, dealing with different problems in obtaining 3D models, enabled us to make some general statements:

- for little artefacts the best results are obtained with focus stacking technique
- light conditions are a key element for SfM technique, so movable and indoor artefacts acquisition are easier using a photographic box
- for outdoor evidences is necessary a specific acquisition to guarantee a good metric precision

Regarding the optimization of acquisition phase, proposed in this paper, it is possible to resume:

- a) for flat objects a motorized slide make the acquisition more quick and precise
- b) the use of video for unmovable artefact both a quick acquisition and good quality for dissemination purposes

In addition, a comparison about measurement aspects and time span for each acquisition is presented in the following table.

	A. The Drawing of Mausoleum	B. The artifacts in the MANaM			C. The Forum sempronii evidences	
		turntable	focus stacking	video	tripods (indoor)	aerial (outdoor)
tools and methods	motorized slide					
outputs	specific study of details	digital library			augmented reality	
accuracy	mm	mm	mm	mm	cm	cm
time of acquisition	medium	medium	slow	fast	medium	fast
quality model	high	high	very high	medium	medium	low

Table I. Comparison among presented case studies

Weak points of the research are data abundance, the use of specific and different acquisition techniques and a big amount of recorded data to obtain high quality models that have to be decimate in order to be compatible with user friendly museum installations.

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