Quick textured mesh generation for massive 3D digitization of museum artifacts

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***Abstract*— The goal of the "3D Icons" European Project, is to provide Europeana with accurate 3D models of Cultural Heritage artifacts. The purpose of this paper is to describe the specific optimized processing pipeline that has been set-up for digitizing a significant part of the Civic Archaeological Museum in Milan (Italy). Many technical and logistic issues for capturing 3D models in a Museum environment are addressed. In such framework the main problem is generating a good result by the technical point of view, minimizing the impact on the usual Museum activity during 3D capture operations, while shortening the processing time to the minimal allowed by the different applicable techniques. This condition led to precise choices related to the 3D acquisition techniques to be used (SfM), and the related data processing.**

This paper illustrates the aforementioned systematic aspects through three practical examples, showing good practices for image capturing and some 3D processing optimizations that allowed to speed the 3D models production at a level compliant to the final goal of more than 500 models in 36 months.

***Keywords*— Range imaging; Photogrammetry; Structure from Motion; Image Based Modeling; 3D-ICONS**

I. Introduction

The 3D-ICONS project (3dicons-project.eu), funded under the European Commission's ICT Policy Support Program and relying on the results of CARARE (www.carare.eu) and 3D-COFORM (www.3d-coform.eu), aims at providing Europeana with 3D models of architectural, archaeological monuments and objects of remarkable cultural importance[1]. The main purpose of this project is to produce around 3000 accurate 3D models at full resolution, suitable to be exported in simplified form in order to be viewable on low-end personal computers and on the web. For reaching this goal an optimized workflow for 3D imaging and modeling has been outlined. The research group of Politecnico di Milano has to deal with the roman structures of the circus that are now included in the modern building of the Civic Archaeological Museum of Milan (MAM) and with all the archaeological objects stored inside it, for a total of 527 models to be created. Taking into account the need to produce a huge amount of models in a quite short period, it was decided to use mainly the Structure from Motion (SfM) technique [1-4] reducing the use of laser scanning, due to the following reasons: i) abrupt reflectance changes on highly texturized museum items (e.g. painted surfaces, mosaics with contrasting colors) generate geometric artifacts in 3D capturing with active triangulation based 3D devices (i.e. laser line or pattern projection). The same changes represent instead a mean for good and robust image matching, making cleaner the related geometric information; ii) the generation of a texturized mesh model has been demonstrated to be far more time consuming with active devices rather than with SfM [5]; iii) some CH materials (e.g. marble, painted ceramics, opaque glass) resulted less optically cooperative with laser than with digital photography.

In this paper a few specific problems in the SfM-based 3D acquisition process (and the adopted solutions) are discussed trough the analysis of three case studies, each based on archaeological objects different in shape, size and material.

II. Data collection and data processing

For image acquisition three digital reflex cameras were used: a 22 megapixel Canon 5D Mark II (36 x 24mm full frame CMOS sensor); a Canon 60D and a Canon 20D featuring 18 and 8.2 megapixel respectively (22.3 x 14.9mm APS-C CMOS sensor). All three cameras were coupled with 50 and 20 mm lenses, according to the needs. The distance to which the images were taken ranged from 0.5 to 3 m due to the position of the objects in the Museum. The GSD resulted therefore between 0.2 and 0.5 mm depending on the camera and lenses used and on the distance from which the images were acquired.

The rooms illumination was based on a mix of spotlights pointed directly on the artifacts and natural light entering in some of the rooms from wide windowed walls, all impinging on the various archaeological items. This gave a not negligible problem of superimposing light sources characterized by definitely different color temperatures: 5000 to 10000 K for the natural light entering from the windows, 2500 to 4000 K for the tungsten lamps. This environment highly influenced the choices during the survey.

Most of the time a few coded targets were used on the scene, and all target-to-target distances were measured with a metallic tape meter.

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[1] 3D-ICONS (3D Digitisation of Icons of European Architectural and Archaeological Heritage). ICT Policy Support Programme. Pilot Type B - CIP-ICT-PSP-PB, CIP5 - Theme 2 DigiCont - Digital content. Grant agreement 297194.

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The data processing was carried out with the Agisoft Photoscan package ver. 0.9.0, a semi-automatic software in which both internal calibration and camera orientation are made automatically, allowing a little interaction to the user. The software implements image orientation through SfM, 3D capturing with dense stereo-matching algorithms and the generation of the final colored mesh.

Several test were done tuning the main operating parameters of the Agisoft software settable in the "Build Geometry" step. The most critical were: i) "Geometry type" (choices: Point cloud/Sharp/Smooth); ii) "Target quality" (5 levels from "Lowest" to "Ultra high" defining the granularity of image matching); iii) "Face count" specifying the total number of polygons of the final mesh (0=all faces).

III. Case study one - Geometry Types Differences

Since the final goal of the project is to produce an high number of models in a short period, one of the main factor was to identify the best pipeline in terms of a reasonable ratio between processing time and accuracy. The first issue to be discussed was about reducing the processing time still having a good quality model in terms of accuracy and visualization.

The test object presented here is the roman stele of Geminus (A 0.9.6742) (Fig. 1a), dated back to the end of the I A.D. Its measures are 174x61x31 cm, it's made of limestone from Vicenza and is part of a funeral monument that has been walled-in since 1860 in the arches of Porta Nuova in Milan [6,7].

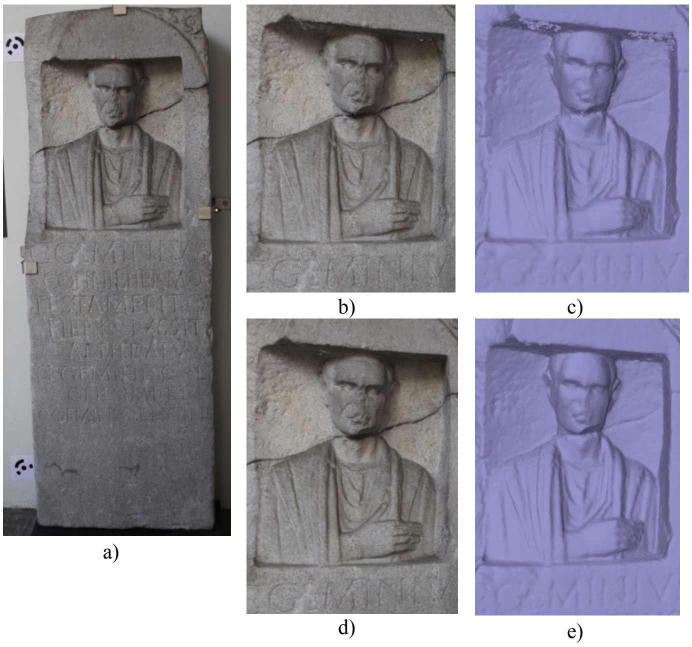


Fig. 1. The stele of Geminus (a). Two models compared with (b,d) and without texture (c, e) obtained with the processing parameter "Sharp" (b, c) and "Smooth" (d, e). Lacking polygons close to the head are evident in (c).

This object is suitable to verify the different meshing algorithm because it has shadowed parts in the niche and the head, and is has also fine sculptured inscription.

The survey was done with 20 images around the object with a Canon 5D Mark II equipped with a 50mm lens, providing a 0.3mm GSD at the chosen operating distance (2.3m approximately). The first processing was set-up with "Geometry type"=Sharp, "Target quality"=Medium, "Face count"=2 million. Then "Geometry type"=Smooth was tested, leaving unchanged all other parameters. The processing time between the two settings was quite the same but the results were much different: the sharp geometry type generated a 3D model accurate but full of topologic anomalies and holes that involved a long and complex post-processing. Configuring the processing with "Geometry type" set to Smooth, all these anomalies were reduced because the 3D point positions were numerically smoothed and their meshing reconstruct a far more complete and consistent model. Such difference was particularly evident in the darker areas, where less image information is available and a precise matching is more difficult. This can be seen in Fig 1c, where above the head and on the side it's easy to see gaps and irregularities due to "Sharp" processing associated with insufficient exposure of the corresponding images. Using the same images and adopting a "Smooth" processing, the mesh quality appear definitely better (Fig. 1e), apparently without significant loss of details.

In order to evaluate quantitatively such loss, a comparison between the two models was done with Polyworks (Innovmetrics), measuring the amount of differences and the presence of possible gaps (Fig. 2). The final deviation between them resulted in the ± 0.3 mm range, that was considered negligible respect to the main details, resulting larger than few mm.

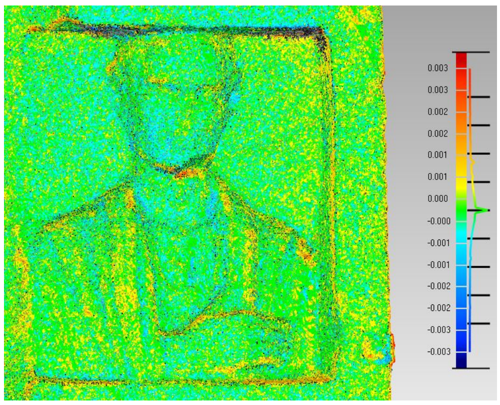


Fig. 2. Comparison map of two 3D models of the stele of Geminus generated with the "geometry type" parameter set on "Smooth" and "Sharp" respectively. Most deviations are included in the range ± 0.3 mm.

IV. Case study two - Camera and Lens differences

The object of the second case study is a sculpted group composed by Aphrodite and Eros with dolphin (A 0.9.1181-1182) dated half of the I-II century AD, in Greek marble, with anthropomorphic real size (96 and 44 cm height respectively), characterized by a medium/high shape complexity [8,9].

The two statues are at a distance of about 15 cm between each other, fixed on the same basement positioned between a wall, 2 pilaster and other 2 unmovable statues (Fig. 3). In this case, the position of the artifacts represented the most significant constrain of the survey. Initially we used a Canon 60D equipped with a 50 mm lens, equivalent to an 80 mm lens on a full-frame camera. At 1 meter of distance (constrained by the short distance in the backside of the statues) the framed area is 28x18,5 cm (GSD 0.125 mm). Due to this configuration it was necessary to shot 70 images to cover the whole surface of Aphrodite's statue, keeping out Eros. Regarding the back side the aperture (usually set 8) gave a limited depth of field providing proper focusing only on a limited portion of the object. In the data processing phase, this caused the failure of the alignment process due to the impossibility to find and adequate number of homologous points on the different images. For the second attempt we used a Canon 20D, again with an APS-C of sensor, but equipped with a 20 mm lens, equivalent to a 32 mm lens on a full-frame camera. In this configuration the framed area at 1 m is about 70x46 cm, and the average GSD is 0.25 mm. Hence it was possible to locate the camera around the object and shoot images framing the entire group of sculptures.

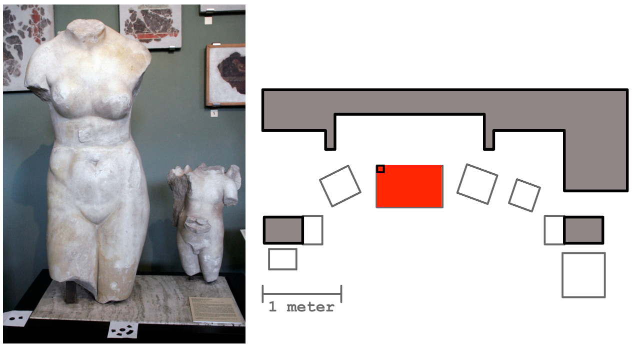
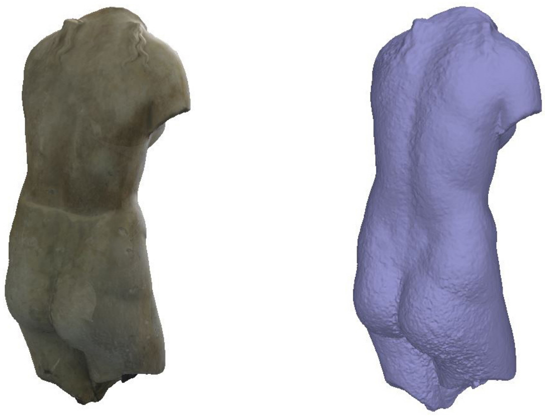


Fig. 3. Sculpted group of Aphrodite and Eros with dolphin and the set layout. The plan highlights the short distance between the object to be detected and the architectural structure and the other sculptures around it

Poor lighting influenced the processing too. The 3D model produced in such conditions might be acceptable just for visualization if shown with its texture (Fig. 4a), while it is not satisfactory if showed just as shaded mesh, because some geometrical artifacts, due to erratic image matching in dark areas, become clearly visible (Fig. 4b, lower part).



a) b)

Fig. 4. Back side of the Aphrodite 3D model, visualized with (a) and without texture (b).

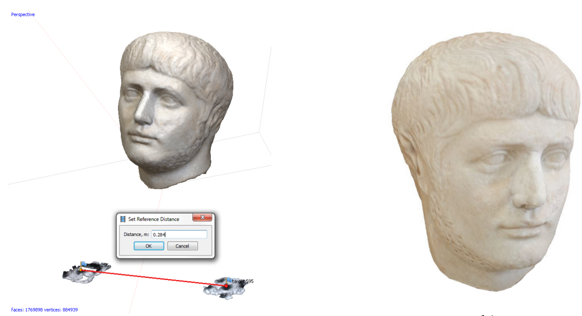
V. CASE STUDY THREE: MATERIALS AND PHOTOGRAPHIC LAYOUT DIFFERENCES

The objects of this case study are two sculpture of man's portrait [8, 9], the first one (A 0.9.1160) is a sculpture of the I century A.D., 27 cm high, realized in clear opaque marble, with fine decoration of hair and beard. The second one (A 0.9.1157) is a precious exemplar of III century A.D., 42,5 cm high, manufactured in bronze casted with lost wax and finishes by burin, chisel and polishing (Fig. 5).

a) b)

Fig. 5. Man's sculpted portrait: a) in marble (ref. A 0.9.1160); b) in bronze (ref. A 0.9.1157).

Both sculptures are usually placed against a wall, but due to their limited size and weight they could be slightly moved in order to gain access all around the artifact exploiting the ideal shooting schema. However in this case the location of each object was such to be illuminated by sources of light at very different temperatures (artificial and natural). For avoiding troubles with color balance, large panels were used, both as shield for limiting the influence of external light and as background to isolate the object from the contest. The benefit of a uniform background was that we could easily generate masks on the images, avoiding undesired geometrical elements, and shortening significantly the processing time too. For scaling the models we used few targets supplied by the Agisoft Photoscan software (Fig. 5a and 6a). Both the imaging campaigns were carried out using a Canon 5D Mark II with a 50 mm lens mounted on a tripod with: fixed aperture; manual focusing; automatic exposure with aperture priority; and operating distance such to give a GSD of 0.18 mm.



a) b)

Fig. 6. Marble portrait: a) scaling the model using Agisoft targets, automatically detected by the software; b) final texturized model.

For the marble head it was used a black panel in order to have a good contrast between the color of the object and the background. Thanks to the material of the object and the possibility to move it from its place, the final model appeared visually accurate (Fig. 6b).

For the bronze head it was decided to do the opposite: since the color of the object was very dark and shadowy the background chosen was white. Due to the high contrast between the dark head and the white background, the image exposure, being evaluated on the average of the framed area, tended to result too low. As a result the darker image areas were not enough exposed to give a sufficient amount of data for the following image matching phase. For this reason some topological errors occurred on the model, for example on the nose (Fig. 7a). The survey was made again, placing a black panel behind the object. The problems due to the excessive light reflection of the background disappeared, and the color of the texture was more balanced and bright (Fig. 7b/c).

a) b) c)

Fig. 7. Shaded surface models obtained using the same camera and layout setting except for the color of the background panel color: a) white; b) black; c) final texturized model obtained with the use of a black panel.

VI. Summary of the Experience and Conclusions

As a project for the implementation of Europeana with 3D models, the 3D Icons project is permitting experiment on a quick 3D acquisition and modeling approach, on different objects, situations, dimension and materials. Having the necessity to produce a high number of models in three years, it was essential to organize the work in a strict workflow that allowed to avoid time consuming operations. The choice of Agisoft Photoscan seemed to be a very good tool for generating good quality meshes from images in a semi-automatic way, giving the possibility to avoid manual selection of homologous points as in traditional photogrammetry, but permitting an acceptable interaction with the user.

After all the tests done, some best practice were highlighted. Regarding the survey, the best choice was to move, where possible, the objects in a place where the lighting conditions were good enough to avoid flickering or huge contrasts among the different part of the objects, especially those with an articulated geometry or parts with deep decoration. In this case, the use of reflective panels helped in having light conditions homogeneous and as much as possible correct. Similar, the use of panels to avoid the background in the images, helping the following masking process, was really useful in clipping the processing time. During the matching phase, parameters choice played an important role: "Geometry type" was set to "Smooth" favoring in this way the topological consistency of the final mesh to its extreme accuracy and limiting the post-processing needed to clean and complete the mesh, however maintaining a reasonable model accuracy; "Target Quality" to "Medium" as best tradeoff between processing time and density of the resulting 3D points cloud; "Face count" was limited to 2 million polygons, that we estimated sufficient to represent with appropriate level of detail all the museum objects considered.

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