3D TECHNIQUES FOR THE SURVEY OF CULTURAL HERITAGES

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KEY WORDS: laser scanning, photogrammetry, cultural heritage, orthorectification, point cloud

ABSTRACT

3D survey of medium and small objects (statues, bas-reliefs, architectonic details) needs to use suitable measurement systems that are able to reproduce, with high resolution, the shape of investigated objects. The high-resolution 3D digital models are a fundamental support for the studying and restoration of works of art and can be used in order to produce replicas by fast prototyping techniques. In this paper the first results of the survey of the metope of temple E and of the small metope of the Selinunte archaeological site, carried out by optical triangulation 3D scanner (TLS), are shown. Both metopes are preserved in Regional Archaeological Museum Salinas in Palermo. In particular, the metope of "*Artemide and Atteone"* and the small metope of "*Europa on the bull"* have been surveyed. The aim of this first experience has been the studying of the problems allied to these methodologies and to the their integration with digital photogrammetric techniques for the total representation of the objects.

1. INTRODUCTION

The archaeological site of Selinunte is one most important and wide of the *"Magna Grecia"*. Situated in the south cost of western Sicily in the Trapani's province (Fig.1), it is a fundamental point of reference for studying and the knowledge of the classic archaeology of western Greek colonies.
The metopes, subject of this work, come from the little shrine of the acropolis "*Europa on the bull"* (6th c. B.C.) (Fig. 2) and from the temple E *"Artemide and Atteone"* (5th c. B.C.) (Fig. 3) situated on an eastern hill. The high number of sculptural fragments found during the archaeological excavations – until today about 300 fragments have been catalogued – leave many problems opened regarding the identification, the restoration and the preservation of these finds.
In this work the most important problems with regard to the survey of sculptural details with 3D non-contact devices have been examined. Particularly the path from the digital surface model to the real prototype has been conducted.
This studying wants to be a first step toward the realization of a digital database in which, the single fragment and the sculpturesque groups constitute a complete archive providing an important contribution for the knowledge, to divulgation of these extraordinary cultural heritages.

Figure 1. Archaeological site of Selinunte

Figure 2. Metope showing "*Europa on the bull"*

Figure 3. Metope showing "*Artemide and Atteone"*

2. 3D SURVEY TECHNIQUES

The instruments suitable to survey 3D data without direct contact with the object are already used from several years: particularly in cultural heritage survey laser instruments have been used. These systems are usually classified in two groups: time of flight (TOF) and optical triangulation 3D scanner. The TOF scanner laser is particularly suitable for the architectonical and geomorphologic survey but it's unsuited for the survey of small and medium objects. These instruments don't provide the requested accuracy to describe the whole details founded in very large scale.
For this kind of objects, the 3D scanner laser, based on the principle of optical triangulation, are used. These systems are composted by two main components: a light laser projector and a CCD camera. The spatial position of sampled points on the light profile is obtained by triangulation, known the measure of geometric parameters (relative positions of laser, camera and point).
The structured light technique provides an alternative solution exploiting the projection of codes on the surface to survey. Generally, parallel lines form the code; from the analysis of image of the code, projected on the surface, it's possible to deduce the x, y, z coordinate of the points of the surface.

3. METOPES SURVEY

The 3D survey of the metopes has been carried out using a optical triangulation 3D scanner Minolta Vivid 9i, which provided, with high accuracy and quickly, a point cloud model of the studied objects.
The instrument is equipped with three lenses: *TELE, MIDDLE e WIDE* to which correspond different focal lengths and precisions (Tab.1).

MINOLTA VIVID 9i - Specifications	
Measuring Method	Triangulation light block method
Light-Receiving Lens (Interchangeable)	TELE: Focal distance f=25mm MEDIUM: Focal distance f=14mm WIDE: Focal distance f=8mm
Scan Range	0.6 to 1.0m (In Standard Mode) 0.5 to 2.5m (In Extended Mode)
Accuracy (X,Y,Z)	+- 0.05 mm (Using TELE lens at a distance of 0.6 m, with Field Calibration System, Konica Minolta's standard, at 20°C)
Number of Output Pixels	3-D data/Color data: 640 x 480

Table 1. Technical specifications of Minolta Vivid 9i

Using the TELE lens and surveying from a distance of 0.6 m from the object, the max obtainable accuracy is of 50 µm. Every single scansion is long 2.5 second in witch about 300000 points are surveyed. Besides, The instrument is equipped with a CCD sensor available to acquire the images of scansion region. These images are characterized by a low resolution (640x480).
The first application regards the three-dimensional survey of the small metope portraying "*Europa on the bull"*. The survey has been carried out from an acquisition distance of 0.6 m from the object. In order to value the data accuracy with regard to using of the TELE and MIDDLE lens, a first test has been carried out on a limited area. In both cases, the captured data preserves a level of detail suitable to the experimentation goal. Therefore, to reduce the number of scansions a MIDDLE lens has been used (Fig.4).

Figure 4. Survey of "*Europa on the bull"* metope

In order to capture the whole data, 35 scansions have been carried out on a surface of 67x84 cm^2. This high number of scansions has been requested to fill the holes in the point cloud model due to the complex geometry of the object. The scansions have been merged two at a time with the software *Minolta Polygon Editing tool 2.0*. The merging has been carried out identifying known features common to two datasets. The software calculates approximate position of one cloud point model with respect to another using common geometric features between the two point cloud models. Performing this operation, first point cloud model has been automatically merged to second model.
The high accuracy of the acquisition allows to get the three-dimensional model with triangular mesh without any pre-elaboration of the data (Fig. 5 and 6).

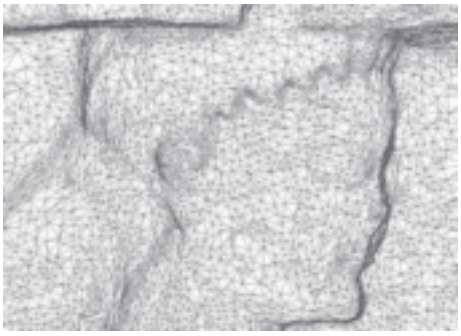

Figure 5. Triangular mesh of a particular of the *Europa* face

Figure 6. Surface model of the metope showing "*Europa on the bull"*

In order to render more manageable the obtained surface a decimation operation has been carried out. This operation allows to reduce the number of triangular mesh keeping high the level detail. A second test has been carried out on the metope of the temple E, showing *"Artemide and Atteone"*.
The artefact is 1.62 m high and 1.32 m large and has been surveyed by a WIDE lens characterized by focal length of 8 mm. The instrument has been put at 1.5 m of the object (Fig. 7).

Figure 7. Survey of *"Artemide and Atteone"* metope

In this way the reduction of the number of the scansions, carried out in relation of the object dimension, has been possible. On the whole ten scansions have been realized. The obtained data has been used to rebuild the surface model (Fig. 8). The qualitative confrontation between the two surface models obtained for the metope of *"Europa on the bull"* and of *"Artemide and Atteone"* has shown, in the second case, a reduction of the geometric accuracy, as the details with reduced dimension have not adequately described.

Figure 8. Surface model of *"Artemide and Atteone"* metope

4. PHOTOGRAMMETRIC SURVEY

The photogrammetric survey has been carried out just for the metope showing "*Europa on the bull"* using a semi-metric digital camera Rollei D7 . This camera has a lens with a focal length of 7.43 mm and is equipped with a 5 mega-pixel CCD sensor. As the object is small (67x81cm) just one block formed of three pictures has been taken from a distance of 2.3 m (Fig. 8).

Figure 8. Pictures of the photogrammetric survey

The block has been oriented using 5 control points and 6 tie points. To evaluate the exterior orientation accuracy 6 check points have been added. The control and check points have been collected by a topographic survey carried out by a total station reflectorless Leica TCR1105 and in order to set the Z-axis perpendicularly to the metope plan, the topographic points have been roto-translated.
The following table shows the residuals obtained after the photogrammetric orientation (Tab. 2).

Residuals [mm]		
Type	**Control Points**	**Check Points**
N. Points	**5**	**6**
X RMS	0,6	2,2
Y RMS	1	2,6
Z RMS	5,1	14,8

Table 2. Exterior orientation Residuals

Then the point cloud model has been set in to the topographic reference system and have been resampled in a regular mesh with a grid-cell 1mm x 1 mm large (Fig. 9 and 10).
In this way producing of the ortophoto of the surveyed object has been possible (Fig.11).

Figure 9. Digital Surface Model

Figure 10. 3D visualization of DSM

Figure 11. Orthophoto with control (red) and check (blue) points

5. THE VIRTUAL MODEL AND THE FAST PROTOTYPING

In order to preserve, to study and to spread works of art it's very useful to produce very high quality virtual model and replicas. These techniques find an important field of application in the documentation and monitoring of the works of art, in the virtual restoration and in the spreading by WEB.
In the carried out experimentation the following results have been produced:

- representation by contour line map of the metopes with equidistance of 5mm (Fig. 12);
- photorealistic raster model (Fig. 13);
- VRML model to be browsed on Internet (Fig.14).

Figure 12. Contour vector map

Figure 13. 3D raster model

Figure 14. VRML model

The realization of replicas of works of art is not a new matter but quite actual for the preservation of the Cultural Heritages.
Until few times ago, artists carried out these operations by hand, instead, actually can be executed by automatic techniques. The modern numeric-controlled milling machines together with the high-resolution 3D scanners allow obtaining replicas from the originals with sub – millimetre accuracy.
Particularly, the carried out experimentation, the milling machine ABAMill 4433 (Fig 15) has been used.

Figure 15. Numeric controlled milling machine ABAMill 4433

This instrument is able to produce replicas with an accuracy of 0.01 mm and it has a working area of 440 x 330 mm large.
From the mathematic triangular model of "*Europa on the bull"* metope, a replica in polymeric resin in 1:2 scale has been produced (Fig. 16). To produce some copies of the replica, a silicon cast is necessary. The elastic material easily allows to penetrate inside the little undercuts and irregularity of the surface, obtaining, in this way, a faithful reproduction.

Figure 17. Replica in polymeric resin of "*Europa on the bull"*

6. CONCLUSION

The executed procedure is particularly suitable for the production both of the digital model and of the real prototype of reduced dimension of works of art. The using of triangulation scanners is requested for an accurate reconstruction of the surface model. Therefore, to make the maximum use of the precision characterizes of the instrument it's advisable to carry out from very short distances (not farther then 60 cm); besides, in order to avoid the presence of regions without data it is necessary to execute a very high number of scansions for each single object. The use of optical triangulation 3D scanner allowed to reduce the pre-elaboration on the unprocessed data to the minimum. The elaborations carried out on the data have regarded just the registration of the scansions and the reduction of the redundancy of the final model.
The photogrammetric survey allowed to obtain the orthophoto of the "*Europa on the bull*" metope, using some images acquired by digital semi-metric camera.
The integration of various survey and representation techniques is often a necessary condition for a correct documentation of cultural heritages.
The produced results can be used for the reconstruction of a digital database that contains the qualitative and metric information of the finds.

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ACKNOWLEDGEMENTS

We would like to thank:

- Mr.Giuseppe Bacchetta, sales manager of ABACUS Sistemi CAD-CAM s.r.l.
- Mr Daniele Molina, 3D sales specialist instrument Systems Division of Konica Minolta Italy.
- Prof. Giuseppe Pellitteri and Eng. Salvatore Concialdi from "Dipartimento di Progetto e Costruzione Edilizia" Università di Palermo
- Dr. Agata Villa, Director of Regional Archaeological Museum Salinas in Palermo
- Eng. Vito Ruffino, for the fundamental collaboration to produce the replica of the "*Europa on the bull"* metope.