

## TRUE DIGITAL ORTHOPHOTO OF THE SAN MARCO BASILICA IN VENICE

Caterina Balletti (\*), Francesco Guerra (\*), Andrea Lingua (\*\*), Fulvio Rinaudo (\*\*)

(\*) Laboratorio di fotogrammetria – CIRCE

Istituto Universitario di Architettura di Venezia – S. Croce 1624 – 30135 Venezia

(\*\*) Politecnico di Torino – Dipartimento di Georisorse e Territorio

Corso Duca degli Abruzzi, 24 – 10129 Torino – Italy

Tel. +39-011.564.7700/7659

Email: [balletti@iuav.it](mailto:balletti@iuav.it), [guerra2@iuav.unive.it](mailto:guerra2@iuav.unive.it), [andrea.lingua@polito.it](mailto:andrea.lingua@polito.it), [fulvio.rinaudo@polito.it](mailto:fulvio.rinaudo@polito.it)

Commission V, WG V/4

**KEY WORDS:** Architecture, Orthoimage, Digital, Metric, LIDAR

### ABSTRACT

The orthophoto is a powerful instrument of representation which combines radiometric and geometric properties. In architectural applications the orthophoto production cannot be performed by using the traditional orthophoto approach. True digital orthophoto is a new technique which uses several images and a complete DEM of the object in order to produce an orthogonal projection of complex objects. All the radiometric information hidden by central perspective in one image must be recovered by other images and the orthophoto production must choose, the best image to be used, one by one. Complete shape description can be easily achieved by using modern terrestrial laser scanner devices. The paper shows the true digital orthophoto production of the central door of the San Marco Basilica in Venice: the result obtained is a complete radiometric and geometric description of the studied object under examination.

### 1. INTRODUCTION

For many years, the orthophoto production of architectural objects has been a difficult problem to solve.

Both analogical and analytical solutions allowed the production of rectifications and orthoprojections (using a plane as reference surface) of smooth objects but, in practice, only the rectification procedure was used in architectural applications.

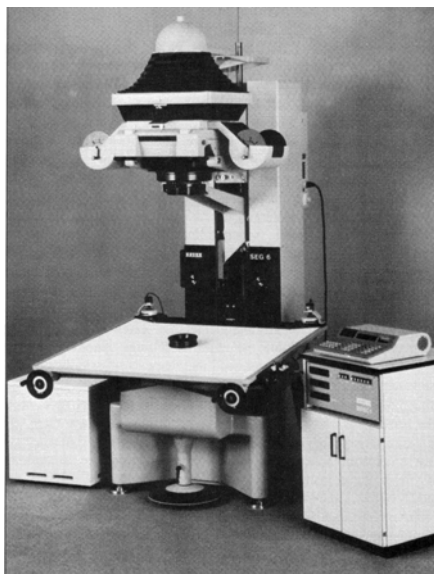
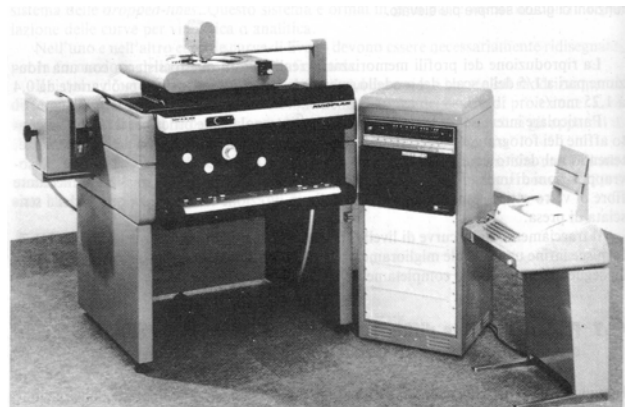


Figure 1. The SEG6 automatic rectifier

This was mainly due to the high degree of discontinuity of the surfaces of standard architecture which causes points with the

same X and Y coordinates but a different Z coordinate to be present on the reference plane.

In order to produce a good shape description the operator have to survey all the break-lines: for architectural object this



solution meant almost the complete survey of the object and caused an enormous growing of the costs.

Figure 2. The Wild AVIOPLAN OR1 analytical orthoprojector

In addition, the presence of a high number of discontinuities causes a large amount of hidden details on the picture to be used in the orthophoto production. Because the analogical and analytical solutions allow the use of only one image, even using the correct description of the surface model the upper details were duplicated and the final product was not a useful representation of the object (see fig. 3).

Digital photogrammetry opened new frontiers in rectification and orthoprojection production both in aerial and terrestrial applications.

As far as architectural application is concerned, the first goal reached was the possibility of producing orthoprojections



Figure 3 . Duplication effect of a single image processing

on non plane surfaces, allowing the orthophoto production of domes, vaults, etc.

In recent years a new procedure of orthoprojection has been proposed: it uses the shape description from a terrestrial laser scanner and a multi image approach in order to solve the problems mentioned above.

## 2. TRUE DIGITAL ORTHOPROJECTION

The true orthoprojection of an object is a correct orthogonal projection of the object itself on a reference plane (or a more general reference surface) based on the simultaneous use of a correct and detailed surface description (DDem) and all the images necessary to describe the entire surface of the object to be projected.

The improvement on the old orthophoto process lies in the simultaneous use of multiple images and by the management of digital images.

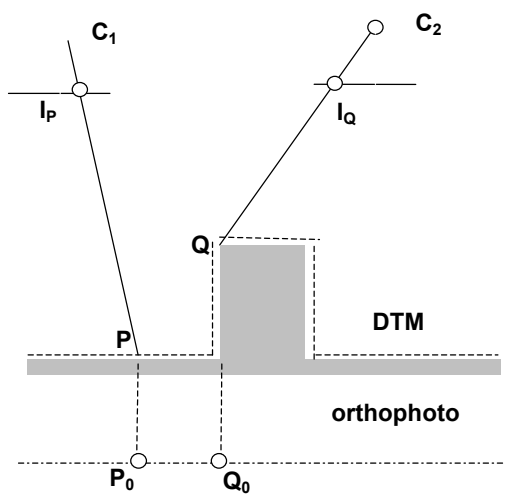


Figure 4. Multiple images process

The multiple image approach allows the elimination of the noises coming from the hidden areas always present in central perspective images, while the direct use of digital images

allows a great economic advantage by eliminating heavy and expensive mechanical instruments.

True orthophoto processing requires a knowledge of the exterior and inner orientation parameters of all the images describing the whole object surface to be projected and the complete description of its shape.

The procedure starts from the highest point of the DEM and looks for the radiometry describing the point itself by using the closest image to the processed point: in order to avoid the duplication effect (see fig. 3), all the pixels which have recorded the same point in the remaining images are then hidden to the subsequent steps of the procedure.

The process runs automatically and finally a digital image representing the desired true orthoprojection is resampled.

## 3. TRUE ORTHOPHOTO OF THE MAIN DOOR OF THE “BASILICA DI SAN MARCO” IN VENICE

The glittering façade of St. Mark's Basilica dominates the vast expanse of St. Mark's Square and stands as a potent symbol of Venice's status as city state and maritime power in the late Medieval period.

The Basilica, which was consecrated in 1094, is the third church to be built on the site since the body of St Mark, the city's patron saint, was reputedly brought here to be buried in 828.

The exotic Byzantine architecture of the basilica reflects the Venetian lagoon's strong trading links with the Orient and the exterior is decorated with marble brought back after the Venetian conquest of Constantinople in 1204.

Five portals decorate the façade. The central one, the object of the true orthophoto generation described in this paper, is formed by three concentric arcs fully decorated both on the interior and exterior surfaces by reliefs produced in XII century (one of the most important works of Italian Romanic sculpture). The mosaic in the bowl-shaped vault of the central portal, represents the Last Judgement and was produced by Liborio Salandri, from a cartoon by Lattanzio Quarena in 1836.



Figure 5. The central portal of the St. Mark's Basilica in Venice

### 3.1 DEM acquisition

To produce a correct DEM of such a complex object it is possible to use traditional photogrammetric plotting. This approach is rigorous in order to describe all the break-lines useful to define the true shape of the portal properly, but it is very expensive and time consuming procedure.

The terrestrial laser scanner technology is, without doubt, the most convenient and fastest way to record the morphology of an object. It is well known that laser scanners are not “intelligent” instruments: they do not record the interesting points in order to define the surfaces forming the object, but they substitute the “intelligence” of a human surveyor by means of the redundancy of the acquisition.

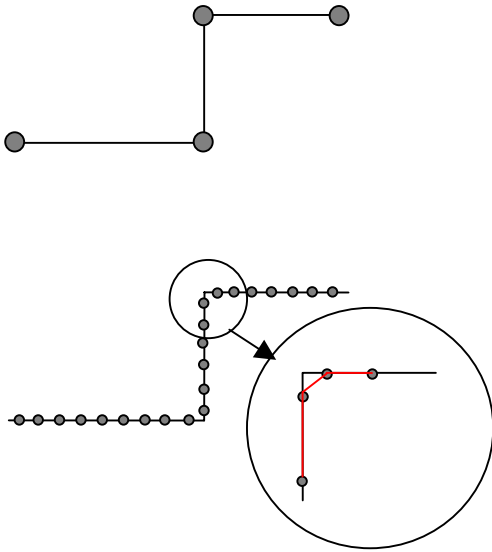


Figure 6. Human and laser scanner survey techniques

The laser scanner acquisition is, in addition, very fast and the results are provided as a series of X,Y,Z coordinates referred to an internal Cartesian system.



Figure 7. The Riegl LMS Z420 scanner and the tilting support.

In order to build up the DEM of the portal a RIEGL LMS Z420 laser scanner has been used. Acquired by Politecnico di Torino the new LMS Z420 is the upgrade of the well known LMS Z210. LMS Z420 is equipped with two different laser: the CLASS 1 laser operate in “high accuracy” mode ( $\sigma_r = \pm 5$  mm) between 2 m and 150 m or in “long range” mode ( $\sigma_r = \pm 15$  mm) between 2 m and 800 m. Maximum scanning ranges are  $80^\circ$  in vertical and  $360^\circ$  in horizontal direction and the beam divergence is of 0.3 mrad. It can be equipped with a tilting support which allows inclinations of the laser scanner adjustable in steps of  $15^\circ$  up to  $\pm 90^\circ$ . The DEM of the central door of the St. Mark’s Basilica has been obtained from 4 different laser scanner acquisitions (see acquisition scheme in Fig. 8). Acquisition n°.4 has been acquired by the laser scanner with its principal axis in a horizontal position. The distances between the points acquired are of about  $5 \div 8$  mm.

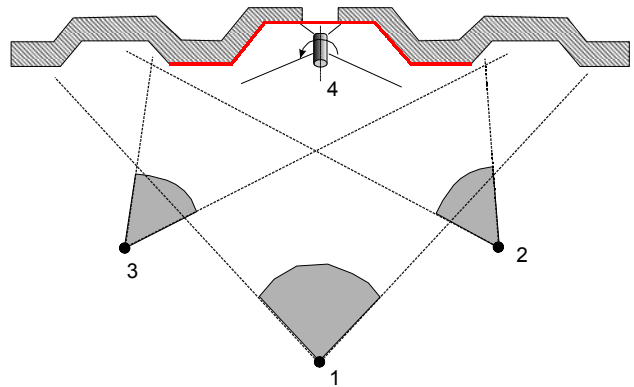


Figure 8. Scheme of laser scanner acquisitions

The four acquisitions have been registered and referred to a terrestrial photogrammetric system. The final “point cloud” has been filtered in order to eliminate noises and regularized in a Dense Digital Elevation Model (DDEM) with regular grid of 10 mm in the median plane of the object. Perspective occlusions cause the lack of information in some areas of the object (see Fig 9). These steps have been performed by using the L.S.R. software developed at the Politecnico di Torino and presented last year [Bornaz, 2002].

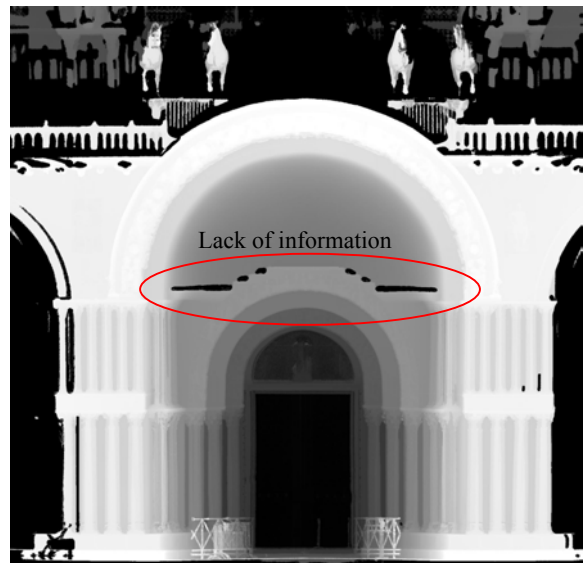


Figure 9. DDEM of the object  
The registration of the scans has been made possible by the



reflecting targets positioned on the portal and the object near to it (see Fig. 10).



Figure 10. Reflecting target on the objects near the central portal

### 3.2 Image acquisition

The photogrammetric images of the central portal of St. Mark's Basilica have been acquired in 2 strips, respectively at 12 m and 16 m of distance from the object, by using a semimetric photographic camera ROLLEI 6008 ( $f = 40$  mm). Figure 11 shows the scheme of photogrammetric acquisitions. Strip A is formed of three images acquired in the normal case of photogrammetry: the mean scale of the images is of 1:400 (see an example in Fig. 12). Strip B is formed of three images acquired by using an inclination ( $\omega$ ) of about 15 gon: the mean scale of the images is of 1:300.

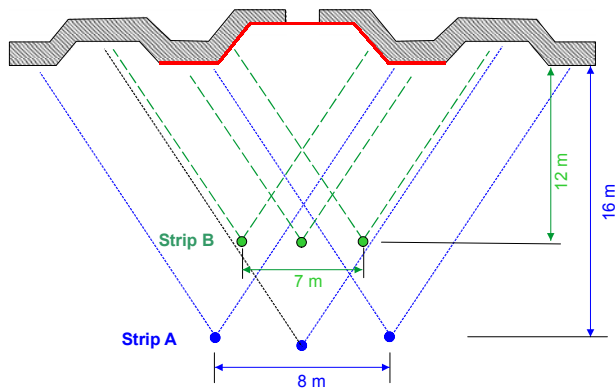


Figure 11. Image acquisition scheme

All the images have been converted in digital form by using the RM2 photogrammetric scanner with a 2100 dpi geometric resolution.

### 3.3 Image orientation

In order to evaluate the orientation parameters of the acquired images, all the targeted points and some other natural points on the structure have been surveyed by using a total station. The point coordinates have been transformed in a terrestrial photogrammetric system.

A photogrammetric triangulation has been performed by using the SVTRIA software (developed by Menci Software and distributed by LEICA). The discrepancies obtained on the control points are less than 4 mm..



Figure 12. The right image of the strip A

### 3.4 True orthophoto generation

The true orthophoto of the central portal has been generated by using the software ACCORTHO, developed by our research group [Boccardo, 2002]. The software was modified starting from the first software produced in order to solve the true orthophoto generation from aerial images.

The DDEM formed by using the laser scanner acquisitions (see par. 3.1) has been referred to the terrestrial photogrammetric system used during the triangulation of the images.



Figure 13. First result of true orthophoto

Observing the first result of the true orthophoto (see Fig. 13) it is possible to detect some inadequacy: the problems arising in the areas where the DDEM showed incomplete description due to the perspective occlusions of the laser scanner acquisitions and in the parts where some obstacle have been recorded by some of the used images.

The incomplete DDEM areas have been recovered by a photogrammetric survey performed by using a digital photogrammetric plotter (SVPLOT by Menci Software). The removal of the noising obstacle has been solved implementing a new topic to the ACCORTHO software.

#### 3.4.1 Noising object elimination

Figure 13 shows three different types of noising objects: the absence of the door, the presence of a bird (accidental obstacle) and the presence of a permanent metal barrie used in order to protect the marble surfaces (systematic obstacle).



Figure 14. Enlargements of the noising obstacles

The presence of the obstacles in the true orthophoto is due to the fact that the ACCORTHO software uses the images which have the principal point closest to the points to be projected.

In our case the obstacles were present on the used images. But the same points have been recorded also by the other images where the obstacles were not present.

The elimination of the noises due to the bird and to the open door can be eliminated because the two image strips have been acquired in two different periods of the day: strip A, early in the morning when the Basilica is closed to visitors (and the door too), strip B in the afternoon. Observing the images it is possible to find images free of obstacles.

The stable division, obviously, has been recorded by all the acquired images, but the portal surface behind it is partially visible in each image.

In order to avoid the use of the undesired areas of the images an "ad hoc" procedure has been implemented in AUTOCAD environment.

The operator has to circumscribe the undesired areas on the images by using the AUTOCAD 3D poly-line command; all the 3D poly-lines must be closed. All the pixels which are inside the areas delimited by the 3D poly-lines are marked in such a way that ACCORTHO cannot use them.

When the software cannot use a pixel on the closest image to the point to be projected, the search is extended to the other images until a "free" (unmarked) pixel is found.

The same procedure can be used in order to eliminate the images of the reseau crosses of the semimetric images.

When all the images have been treated, the final true orthophoto can be generated (see fig. 16). Using a standard PC PENTIUM IV, the true orthophoto generation takes about 15 minutes.

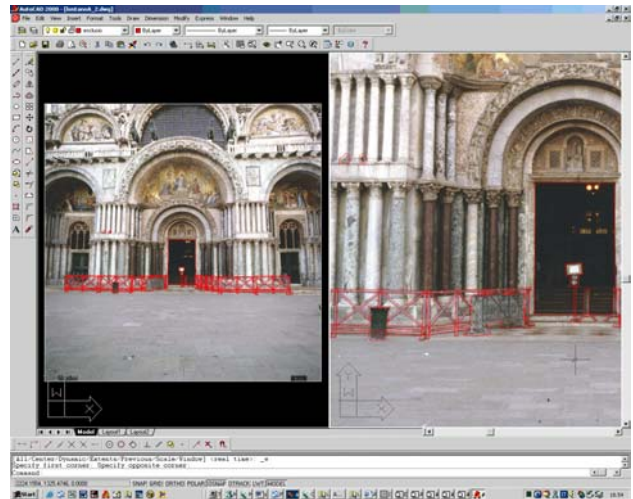


Figure 15. 3D poly-lines generated in order to eliminate the presence of the obstacles.

## 4. CONCLUSIONS

The digital image processing applied to the photogrammetric procedures allows the development of new techniques.

The true orthophoto is a powerful and innovative solution for a complete geometric and radiometric representation of architectural objects.

ACCORTHO has been implemented in a MicroSoft WINDOWS (Visual Fortran) environment and can be used by non experts.

The true orthophoto generation of the central portal of the St. Mark's Basilica in Venice demonstrates that even when the object is very complex a correct solution for a complete representation can be found.

The procedure implemented and tested is a good example of laser scanner and digital photogrammetry integration which requires limited financial outlay.

## REFERENCES

- Kraus, K., 1994-1996. *Photogrammetry Voll. 1,2*. Dümmlers Verlag, Bonn.
- Boccardo P., Dequal S., Lingua A., Rinaudo F., 2001. *True digital orthophoto for architectural and archaeological applications*. International Archives of Photogrammetry and Remote Sensing. vol. XXXIV - 5/W1, pp. 50-55
- Bornaz, L., Lingua, A., Rinaudo, F., 2002. *A new software for the automatic registration of 3D digital models acquired using laser scanner devices*. Proc. "Scanning for cultural heritage recording" pagg. 52-57.
- Boehler W., Heinz G., Marbs A., Siebold M., 2002. *3D Scanning Software: An Introduction*. Proc. "Scanning for cultural heritage recording" pagg. 47-51.
- El-Hakim, S., Beraldin, J.-A., Picard, M., 2002. *Detailed 3D reconstruction of monuments using multiple techniques*. Proc. "Scanning for cultural heritage recording" pagg. 58-64.



Cantoni, R., Vassena, G., Lanzi, C., 2002. *Laser Scanning and Traditional Survey Integration to Build a Complete 3D Digital Model of "Sagrestia dell'Archivio di Stato a Mantova"*. Proc. "Scanning for cultural heritage recording" pagg.105-109.

#### AKNOWLEDGMENTS

The research has been financed by Italian Ministry of Education, University and Research (MIUR) project PRIN2002 (Nat. Resp. Prof. Carlo Monti – Research Group Resp. Prof. Fulvio Rinaudo).



Figure 16. True orthophoto of the central portal of the St. Mark's Basilica in Venice