Computer Vision and Photo Scanning

V. Cardone[1], M. Giordano[2]
Department of Civil Engineering, Faculty of Engineering, University of Salerno, Salerno, Italy

Abstract-**The photo scanning technique for the architectural survey sees the photo captured like data input not only metrically valid, but also full of chromatic information, operating directly with 'coloured point' clouds. It has been possible, therefore, to obtain a point cloud representation with the software ZScan 3.4.4 from Menci, and consecutively to produce orthophotos with the Z-Map Laser 3.6.42 application (from the same software-house), that integrates a complete CAD environment, in which the functionalities for advanced design and the raster editing are available. The methodology has been tested for the survey of the "San Pedro de la Nave's" Church, in province of Zamora (Spain). The experience, conducted within an Erasmus agreement between the Department of Civil Engineering of the University of the Studies of Salerno and the "Escuela Tecnica Superior di Valladolid" [1], was born as an attempt to verify such methodology, and the relative application as alternative or as an addition to the most consolidated digital survey techniques.**

The results have then pushed to confront raster vectorial knowledge – orthophotos of the facades represented in overlay on a traditional graphic representation – for a geometric-dimensional analysis of the architectonic manufactures.

Keywords – Computer graphics, image matching, survey.

I. INTRODUCTION[1]

With the artificial production of high resolution images, a radical change in the elaboration of the graphical models has being taken place. With the Computer Graphics, in fact, we are not only experiencing a new powerful instrument or a new sophisticated technology, but a brand new form of graphical expression [2].

Within the handling of infographic images, many traditional concepts endure deep transformations while being used in a completely different way, with elements nearly abandoned (as an example the colour) and brand new graphic parameters: *infographic parameters* (such as brightness, opacity, reflection, and intensity). It is not an exaggeration to state that the colour is the more congenital traditional variable to the infographic representation and in absolute one of most effective, with applications and potentialities almost infinite.

With these new computer graphic restitution procedures, the line has lost that decisive nature which previously it had in the graphical representation, technical and not, of which it has been an essential element: indeed the more important, despite the fact it was pure abstraction.

The primary units of the representation are reduced to a single one: the point. It can be clearly stated – as Nicholas Negroponte, one of the pioneers and guru of the computerized design, did - "a pixel constitutes the molecular level of the graphic" [3].

With reference to these topics, an innovative survey method named "photo scanning" is testing. This method works on coloured point clouds, acquired by a short number of snapshots.

The implemented methodological procedure has been analyzed and verified for survey of "San Pedro de la Nave's" Church, in province of Zamora (Spain).

The church, object of studies, can be dated back to the 680 A.D., represents one of the most representative evidences of the Spanish Visigothic architecture. Moved in 1930 from its original site in the basin of Esla River, where it was going to be covered by water, the church was dismantled stone by stone to then be reassembled on the higher edge of the same valley. This permitted the study to get deeply acquainted with the original structure of the building which presents rectangular plan divided in three naves: the center and the transept one have the same height and width and intersect with each other, forming square space delimited by 4 arches concealed by a tower. The scanning of the pillars separating the naves and the transept describes a Latin cross, emphasized from the addition of external bodies; all enclosed in thick walls made by chiseled squared stones. This is an architectonic complex with perfectly balanced volumes that, thanks to its state of conservation and its interesting sculptural ornament, attests the maturity achieved by the Visigothic Architecture in the seventh century. This unusual movement has placed, alongside the constructive wisdom inherited from the Roman, the variety and the sculptural wealth of friezes with oriental inspiration, where the geometric patterns prevail on the figurative representation of floral decorations [4].

The church for its geometric and construction characteristics has turned out to be an ideal study case to verify the use of the photo scanning technique. Its articulated space configuration, given by the different aggregation of volumes, has made possible to experience this methodology, and particularly to locate parameters of control in the registration phase, so that the three-dimensional model, composed from different point clouds, was able to generate a sole entity, from which therefore obtaining, like final outcomes, the relative orthophotos. Moreover, exhibiting building walls stratified with squared ashlars of different dimensions and colours, it has been possible, in the phase of post-process, to analyze and to quantify the value of the variables on which to act in order to obtain a chromatic restitution very close to the truth.

The data processing is based on an algorithm of multifocal corrections through which images are re-sampled according to planes of variable depth and identified by a number of feature such - whose dispositions influence the successive calculation phases - to interest homogenously the entire photogram. The correction is conducted by a process of image-matching multi-ocular of dynamic programming: a search algorithm of the homologous features, acting simultaneously on the three images, takes advantage of the chromatic RGB components and leads to the reconstruction of the photogram orientations [5]. The survey application has demanded the analysis and the verification of a specific methodological procedure, than it has been articulated in the following phases: plane of the shooting stations also according to their environmental context; realization of the photographic images taken with a digital camera (Nikon D100 fixed optical Nikkor with 28 millimeter); reconstruction of internal-external orientation where, with semi-automatic or automatic procedures, the various images in a prefixed reference system have been correlated; generation of a three-dimensional model through specific algorithms (matching area based/feature based), displayable like point clouds in a wireframe modality or with texture; DEM and orthophotos generation; editing of the georeferenced images and, at last, the orthophoto mosaic with the export of the result obtained.

II. METHODOLOGY[2]

A crucial moment has turned out to be the choice of the viewpoints, which vary according to the optical used, to the level of detail that is required to achieve and to the dimensions of the architecture to survey. For every location, after opportunely fixing the inclination of the camera main axis, three snapshots (*triple*) taken from left towards right, symmetrical to the photogrammetric bar (*Baseline*), must be carried out; often it has turned out necessary to acquire, for every location point, more than one *triple*, according to the height to survey. The base algorithm elaborates only the portions of images simultaneously present in the three photograms; it is therefore fundamental, in order to obviate cases of disparity or problems of insufficient special information, that between the first and the third shoot there must be at least an overlap zone above 60%.

The main application limits of this instrumentation are due to the distance of the focusing (that defines the so-called ‘minimal distance’ from which it is possible to operate), to the focal, and therefore the field of view of the camera (that establishes ‘the optimal theoretical distance’ of the shooting stations), to the optical and the length of the bar that determines the ‘maximum distance’ from which it will be able to operate (a value of 10÷12 m it has be thought acceptable). To smaller distances, creating wide areas of overlap, a greater level of detail is obtained, but there is also the necessity to realize more *triple* in order to cover the entire surface to survey; the accuracy values, that are the maximum precision in depth, can be easily labeled in relation to the *Baseline* and the shooting distance. Although such technique theoretically does not need any fiducial point or preliminary measurement, a direct survey of support, using natural or artificial targets, can facilitate the successive operations of recording and mosaic, other than be an useful instrument for supporting and geometrical checking of the model. For example, operating with targets it is possible to push the use of the instrumentation up to 16 m (also 20 m, in the event of shoot with axis nearly horizontal).

From the results attached to this work is possible to infer that the system - and the implemented methodology - concur to obtain a good reconstructive quality of the form and of the colour; as it happens also with the most traditional laser scanner, multiple factors, such as the shooting distance, the typology of surface, the lighting system and, not least, the systematic error of the instrumentation can determine the presence of points with a wrong elevation (*noise*). However, if the surface to document presents a certain continuity and regularity, it can be assumed that the 3D coordinates of a generic point of the cloud are strongly correlated to the values of the limit points. Therefore, it is possible to reduce the *noise*, in other words to eliminate eventual ‘dirty’ data, working on the command *Noise Reduction* and establishing the amplitude of the surrounding with which every point it must relate in the generation of the three-dimensional model; in the case of flat superficies, such range will be widened in order to privilege the uniformity and the cleansing of the final model.

According to the *Area of Interest - AOI*, a various resolution step (*Step)* can be assigned; this represents the number of sufficient pixels to generate a three-dimensional point in a digital space: at the diminishing of such value, the *Ground Sample Distance - GDS* is reduced. Which means that the medium distance of the 3D points on the generated model, and the coloured point clouds will result denser and more defined, although heavier to manage and to elaborate in terms of the dimension of the files generated. It is however preferred to generate dense 3D models, in order to guarantee, also in absence of texture, the perception, the accuracy and the degree of definition adequate to the detail scale.

In order, then, to associate the texture to the model it is necessary to pass to the successive phase triangulation and generation of the mesh. In the definition of the polygonal model it will be established a threshold value α, that it represents the maximum diameter of the circumference that circumscribes the triangle of the mesh: only the points closer to the limit therefore fixed will be interpolated. If a very small α is defined, a denser mesh with many holes will be defined; vice versa, a too much great value will generate polygons not coplanar, even if with few information gaps**.**

The time employed to generate every point cloud will vary according to the values of the *Step*, the dimension and the number of the defined *AOI*, the chromatic qualities of the modeled surface, the value of *Noise Reduction* and the presence or absence of the triangulation calculation. The model obtained can be exported for the successive phases of editing, also with automated procedures, to generate planes, sections, profiles, contour lines, DEM, etc. It is also possible to use Z-Map Laser, like anticipated, for the operations of alignment of the different point clouds, the correction of the errors, the creation of orthophotos and the creation of vectorial graphics [6].

Once the 3D model is loaded in the Z-Map Laser, a sole entity imported on a specific layer is obtained, according to necessities; it can be visualized in different modality (points, surface, wireframe). Once a reference model is found, the *UCS* or the worktop, where all the entities will be projected, will be defined. The successive phase of registration allows the geo-referencing of contiguous models through the collimation of homologous points, obtaining therefore a new roto-translation entity regarding the precedence model; this elaboration can be facilitated through the informations that are obtained from the texture, especially for the objects that represent chromatic attributes rather than geometric. Once the manual georeferencing is terminated, it is possible to refine it through an automatic procedure based on *ICP* algorithm (*Iterative Closest Point*), that applies a rigid roto-translation of the point clouds, considered mobile, in order to improve the overlap with the cloud considered fixed.

The method follows the procedure “Point-to-Point”, which differs to the method “point-to-plane”: in both cases, the registration happens through the search of the minimum of an objective function. In the first case the function is given from the sum of the squares of the distances of the “corresponding points” of clouds: to every cloud’s point to register, and therefore mobile, the algorithm associates the point closer between those of the fixed cloud contained inside of a sphere of given radius. Once the procedure is completed for all the floating cloud's points and all the squares of the relative distances are calculated, the value to minimize, moving with some rigid rototranslations, the floating cloud is obtained. In the second method for each point of the floating cloud the points of the fixed cloud, closer to the perpendicular outgoing point, are associated: points which characterize a plane called “best-fit”. The objective function, in this case, is to minimize the sum of the squares of the distances between the points of floating cloud and the corresponding “best-fit” planes passing for the fixed cloud’s points. Such algorithm allows a convergence with a number smaller of iterance, since the minimum of the relative function will be determined in the plane.

Once the registration is completed, and a determined number of points are selected, it is also possible to go back to the mean-square error to the standard deviation of the repositioning. The minimal set of very close points, although it involves a negligible mean-square error, it is not effective as the geo-referencing it would not turn out to be valid for the entire image; vice versa to an excessive dense set of points, if not opportunely chosen, a meaningful increment of the mean-square error it will correspond. Therefore, with the aim to reduce this kind of error it is opportune to choose the points which are distributed more uniformly possible on the entire image, starting from the four apexes and gradually proceeding via a regular mesh; doing so, it will avoid the image turning out non-homogenous in the final correction.

The Z-Map Laser application, in the phase of registration, does not include the automatic fusion in a sole three-dimensional model of different points clouds; at the occurrence, it has been considered necessary to execute the merge operation with software of specific reverse engineering, like Polyworks or Geomagic (during the last period of the experimentation, it has been elaborated a new module of extension, Z-Block, for the compilation of the 3D models previously georeferenced) [7].

The final phase of the work has seen the generation of orthophotos and DEM: these allows us to handle the results with various corrective tools typical of computer graphical, in a fast and immediate way, correcting, as an example the errors originated in the phase of scanning. Once all the models were georeferenced, and the single orthophotos was generated, it turned out necessary to mosaic them in order to obtain just one elaborated final graph for every facade. This operation demands the appraisal, inside overlapping areas, of the optimal distance of the splice lines, said *Cut Lines - LT*. For the automated mosaic of images, the implemented software has two algorithms for the calculation of the *LT*: *Dynamic Programming Path*, generally used for the aerial orthophotos, and *Close Point Locus*, more indicated for orthophoto mosaic. This last one, based on the *Voronoi Diagram*, allows to manually modify the course of the *LT*, with the aim to blend the areas of overlap between orthophotos. Before proceeding with the mosaic, a series of parameters will have to be set up, such us the amplitude of the overlap zone and the image of reference for the balance of the colour; in addition, activating the algorithm *True Orthophoto*, it is possible to ‘fill’ the shadow zones, integrating information from the orthophotos available with other angles shot [8].

III. CONCLUSIONS[2]

During the scanning phase, 26 stations for a total of 78 photo captures have become necessary: for every facade it has been carried out between 8 and 10 *triples*, keeping in mind that every *triple* of angle would have contributed to the restitution of the orthophoto of two facades.

The captures have been carried out proceeding in a clockwise direction, with a mean distance of approximately 10 meters from the facades, using the entire length of the *Baseline* equal to 90 cm (the photogrammetric base is a micrometric guide of steel). The height of the central nave has involved, in some locations, the execution of more *triples* in vertical, with consequent inclination of the axis of the camera; however, the zenith angle has been limited - making reference to natural target - to only two values [9].

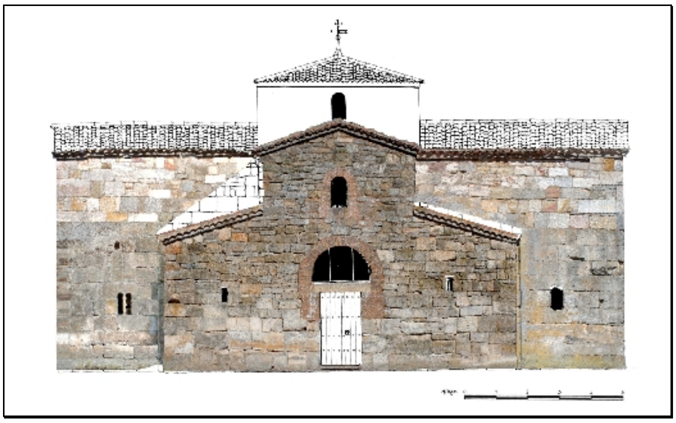

Figure (1): Orthophoto Ovest.

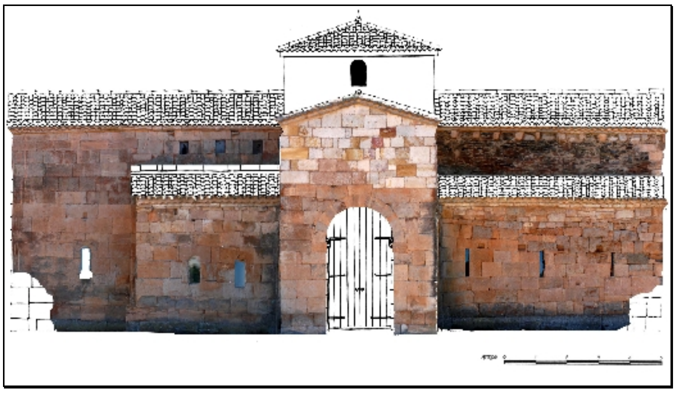

Figure (2): Orthophoto Nord.

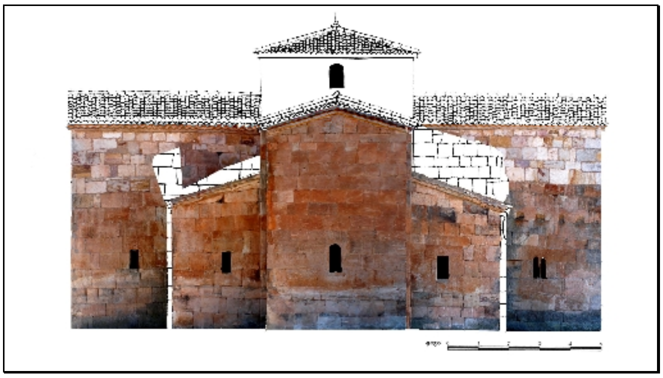

Figure (3): Orthophoto Est.

Figure (4): Orthophoto Sud.

In ZScan mode they have been loaded in total 22 *triples*, the remaining 4 have been discarded as redundant, since lacking any additional information. Of the photographic *triples* imported, 6 *triples* of angle do not appear in the final restitution, as they have been used exclusively as support in order to join models that had very few homologous points. The initial correction, based on a process of image-matching, has allowed, for each *triple*, the reconstruction of the internal orientations of the photograms, eliminating the imperfections due to micro movements of the tripod or the bar (although every shoot has been taken with a timer).

In order to reduce the calculation times, for every *triple* it has been set a *Step* of resolution equal to 4: in order to produce images in scales 1:50, therefore with a degree of relative resolution equal to 2.5 cm, it has been necessary to empirically characterize a value of the *Step* which was relative to a *GSD* value of 1÷2 cm. In fact, only with *GSD* values inferior to the relative degree of resolution it is possible to not represent the distance between the points of the model 3D and so to appreciate the point cloud as continuous one [10].

Moreover, in order to distribute uniformly on the vertical plane surface surveyed the parameter *Noise Reduction* it has been set up as *Very High*; the area of surveying it has been widened in depth, activating the *Full disparity estimation* parameter. The point clouds, thus obtained, have been imported in the Z-Map Laser for the successive registration step.

In this cases, in order to obtain the orthophotos like the final graphics, for every facade, the reference model has been fixed according to the areas with greater distribution of homologous points, and on these areas the *UCS* has been set up by selecting a set of check points; on this 3D model, then it was continued with the registration, using also information obtained from the texture. The process of georeferencing has been always completed with the implementation of the automatic procedure, accepting as valid only the elaborations that introduced a value of the mean-square error inferior to 1 cm. The orthophotos have been generated, from the geo-referenced models saved and imported in new layer in the Z-Map Laser. But before to patch the mosaic of the single restitution, the algorithm *LPV* for the automatic calculation of the *LTs*, has been implemented, proceeding, in order to attenuate the separation zone, to manually modify the same restitution, moving them, when possible, on elements already detached from the surface (contour of stones, windows, etc).

It has turned out indispensable, in order to minimize the eventual variations of chromatic intensity and to equalize the images, to identify during the patching process a photo of reference for the balance of the colour; regaining, instead, the resolution of the final mosaic, it has been chosen the option that allows to conform all the dimensions of the single orthophotos with the one with higher definition. The results have then encouraged to confront raster and vectorial knowledge - orthophoto of the facades returned in overlay on a traditional graphical representation [11] - for a complete study of the volumetric distribution and the external proportions of an important example of the Spanish Visigothic heritage.

REFERENCES

[1] The coordinator of the exchange activities of the Erasmus program is the prof. V. Cardone, Dean of Engineering Faculty of Salerno and President of Conference of the Deans of the Italian Engineering Faculties.

[2] V. Cardone, *Modelli grafici dell'architettura e del territorio*, new edition, CUES, Salerno 2008.

[3] V. Cardone, *From Descriptive Geometry to CAD*, in M. Emmer *Mathematics, Art, Technology and Cinem*, p. 67-76, Springer-Verlag, Berlin Heidelberg 2003.

[4] L. Vicente y Romea, *Historia de la arquitectura cristiana-española,* tomo III, ed. Espasa Calpe, Madrid 1930.

[5] F. Ceccaroni, *ZScan: generazione di modelli 3D per la ricognizione metrica e radiometrica dei beni culturali tramite immagini,* Technologies Exploitation for the Cultural Heritage Advancement (TECHA), Cangemi Editore, Roma 2008.

[6] V. Iannizzaro, S. Barba and M. Giordano, *Nuvole di punti vs Nuvole di pixel*, Le vie dei mercanti. Rappresentare la conoscenza, La scuola di Pitagora Editrice, Napoli 2010.

[7] S. Barba, *Tecniche digitali per il rilievo di contatto,* CUES, Salerno 2008.

[8] The methodology has been tested in range of the exchange activities of the Erasmus Placement, academic year 2009/10, in the Applied Physics Department of the ETS of Valladolid, tutor, the University prof. J.I. Sánchez Rivera. The graphical reconstructions were done by ing. M. Giordano.

[9] The gathering phase has been executed within the activities of the University of Salerno's annual scholarship "for the frequency of courses and the development of improving activities carried out abroad": scientific responsible prof. S. Barba, grant beneficiating F. Fiorillo.

[10] S. Barba, F. Fiorillo e J. I. Sánchez Rivera, *La propagazione dell´errore medio della media nei fotopiani*, in Atti del XIII Congreso Internacional de Expresión Gráfica Arquitectónica 'Nuevos medios gráficos, nueva arquitectura', Editorial de la Universitat Politècnica de València, 2010.

[11] A. M. Rodríguez, *San Pedro de la Nave,* Colegio Oficial de Aparejadores y Arquitectos Técnicos, Zamora 1980.