

DIGITAL PHOTOGRAMMETRY AND TLS DATA FUSION APPLIED TO CULTURAL HERITAGE 3D MODELING

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ABSTRACT

A great number of papers have been so far published about the comparison and the integration between terrestrial laser scanning and digital photogrammetry, as surveying and 3D modeling techniques. Though most of the works report about their application to Cultural Heritage, achieved results have shown that these two technologies can supplement each other in creating high-quality 3D recordings and presentations: laser scanning can produce the dense 3D point-cloud data that is required to create high-resolution geometric models, while digital photogrammetry is more suited to produce high-resolution textured 3D models representing just the main object structure. It should be noted however that in many cases, fusion or integration of both surveying techniques is regarded only as the application of digital images onto the laser scanning-based 3D model and/or the production of orthophotos.

It is well known that for complex architectures, no modeling technique by itself can efficiently and quickly provide a complete and detailed 3D model: a hybrid approach is required. In the view of an insight investigation on this topic, this paper reports on the study of merging digital photogrammetry and laser scanning to produce a unique detailed 3D model of a complex historical building. The basic shapes (e.g. walls and other main structures) were determined by image-based methods using a 7Mpixel digital camera while fine details or more complex shapes were surveyed with a TOF laser scanner. Adopted data collection procedures and modeling issues, related to the integration of the different datasets, will be discussed. A final textured 3D model and virtual flights over the historical building will be also presented.

1. INTRODUCTION

A great number of papers have been so far published about the comparison and the integration between laser scanning and digital photogrammetry, as surveying and 3D modeling techniques. Most of the works report about their application to Cultural Heritage; a wide variety of objects, like small and large statues, historical buildings, whole archaeological sites, have been scanned and modeled for different purposes such as preservation, as-built documentation, reconstruction and museum exhibitions. Achieved results have shown that these two technologies can supplement each other in creating high-quality 3D recordings and presentations: laser scanning can produce the dense 3D point-cloud data that is required to create high-resolution geometric models, while digital photogrammetry is more suited to produce high-resolution textured 3D models representing just the main object structure. In many cases, fusion or integration of both surveying techniques are regarded only as the application of digital images onto the laser scanning-based 3D model and/or the production of orthophotos. However some exceptions to this common approach should be mentioned. For example in (Guidi et al., 2003) and in (Vozikis et al., 2004) the photogrammetric survey is used, with different strategies, to improve the point cloud registration. Digital images have been also used to extract information on edges and linear surface features in order to bridge gaps in the laser scanner data and to add new details to improve the realistic perception of the scene (Alshwabkeh et al., 2004).

In 2004 the authors carried out a joint project (Guarnieri et al., 2004) for the comparison between digital photogrammetry and laser scanning techniques applied to the survey of an ancient church, featuring a simple geometry composed by

both planar and curved surfaces, located in the surrounding of Padua (Italy). In the view of an insight investigation on this topic, this paper reports on the studies of merging digital photogrammetry and laser scanning to produce a unique detailed 3D model of a complex historical building. In fact, for complex architectures, no modeling technique by itself can efficiently and quickly provide a complete and detailed 3D model (El-Hakim et al, 2002). Usually the basic shapes (e.g. planar surfaces) are determined by image-based methods while fine details (e.g. reliefs) by range sensors. On the other hand, the basic shapes can be also determined with a quick scan and the fine details by means of dense image matching procedures. In this investigation the former approach was tested, combining image data from a 7Mpixel digital camera and range data from a TOF laser scanner. A similar approach has been already described in (Beraldin et al. 2005) and in (Valzano et al, 2005). However in such cases range data were acquired only with optical (triangulation-based) laser scanners, no TOF systems were employed.

In the following sections the adopted data collection procedures and modeling issues, related to the integration of the different datasets, will be discussed. A final textured 3D model and virtual flights over the historical building will be also presented

2. SITE DESCRIPTION

The Brenta Riviera is a group of villages and green areas lying along the ancient bed of the river that joins Padua and Venice. The ideal mainland extension to Venice, considered almost one of the quarters of the city of the Lagoon, the golden era of the Brenta Riviera ran from the 16th until the 18th century, during which time it became an elite holiday

resort for the rich and noble families of Venice. The villas were first built on the Riviera in the 15th century, when the territories of Venice were extended to the mainland. Growing difficulties in trading with the East and the discovery of America led the Venetians to invest their capital in large estates. The beauty of the Brenta landscape, the fertility of the soil and the easy access to the area by boat all drew the attention of the Patricians down the river Brenta. Alongside the river elegant houses were built to allow the families to enjoy their holidays during the best months of the year. The different styles of villa architecture are outstanding, varying from 16th century austerity to the free-running imaginative styles of the 17th century and the more rational buildings of the 18th century. Villa Giovanelli represents one of the most important buildings among these Venetian villas. Located close to the city of Padua, it was erected in Palladian style and enlarged in 1738, by adding the great staircase in the main façade (Fig. 1), when Amalia from Poland stopped here during her travel to Neaples where she was going to marry Carlo di Borbone.



Figure 1: View of the south facade of Villa Giovanelli



Figure 2: View of the north facade of Villa Giovanelli

A partial restoration work of the villa's interior has been recently undertaken in order to recover some frescoes hidden by a layer of plaster. An analogous project for the outside walls is under development.

The Villa represents a challenging task for the 3D modeling given its complexity: beside pretty regular geometry of the main body of the building, architectural details such as columns, turrets, statues and stairs are present as well. Therefore, in order to create a unique 3D model of the whole exterior of the building, with enough quality of geometric and

color information, a hybrid method exploiting different independent surveying techniques was adopted. The full workflow, based on digital close-range photogrammetry and terrestrial laser scanning is described in the following sections.

3. DATA COLLECTION

As the starting point of the work was the generation of both photogrammetric and laser scanner-based 3D model of the villa, different surveying techniques were employed.

3.1 Photogrammetric data acquisition

High-resolution digital images of the villa were captured for photogrammetric processing using a *Casio Exilim 750* camera. This is a 7.2 Mega pixel camera with a 1/1.8" CCD sensor size and a focal length ranging from 7.9mm to 23.7mm, equivalent respectively to 38 mm and 114 mm for a 35mm format size. About 300 images were acquired in one day keeping the camera at the minimum focal length, while the image resolution was set at the highest level (3072 x 2304) in order to acquire good quality textures. Standoff distance ranged between 5m and 40m according to the geometry of the building and the need to get at least an image side overlap of 50%.

At this stage, beside photogrammetric data, coordinates of a few ground control points (10) were measured in reflectorless mode with a Leica TCR 705 total station, as well. These points have been successively employed both for the photogrammetric processing and to bring the two models in a common reference system. The latter operation was necessary in order to merge the models in a unique digital 3D product.

3.2 Laser scanning data acquisition

The survey of the exterior of Villa Giovanelli was performed with a high precision terrestrial laser scanner (TLS), the Leica HDS 3000 owned by Cirgeo. Based on TOF measuring principle, this scanning system allows for a larger Field of View (360° H x 270° V) thanks to the adoption of a dual-window, ensuring in the same time a low beam divergence (< 6 mm @ 50 m) and a good measuring accuracy (6 mm @ 50 m), as in previous laser system (formerly Cyrax) 2500. Furthermore, beside intensity of reflected beam the HDS 3000 is able to acquire RGB data at different user selectable pixel resolutions (low, mid, high), through the 1 Megapixel built-in CCD camera.

Point clouds were acquired with a spatial resolution of 1 cm, this value was chosen as an acceptable compromise between level of detail of the final 3D model and computing resources needed for data processing. Thoroughly 50 scans were collected in different days, resulting in a 30 million points dataset.

4. DATA PROCESSING

In a first stage, the data collected from both surveying methods were processed independently, so that two different 3D models as complete as possible would be created from corresponding datasets. In a second stage, such models have been properly merged together exploiting the editing capabilities provided by Rhinoceros software, in order to achieve a unique virtual representation of the villa.

4.1 3D Model from Photogrammetric data

Prior to data capture, the camera's interior parameters were recovered using the Camera Calibrator tool of PhotoModeler Pro 5 software. To this aim 12 images of a predefined calibration grid (Fig. 3) were acquired from different viewpoints; during this stage 3 photos were captured with the camera rotated at 90° around its optical axis in order to improve the accuracy of the estimate. Through the automatic recognition of 4 markers placed at the corners of the grid and the application of a Bundle Adjustment (BA) procedure, interior parameters were successfully computed as shown in figure 4.

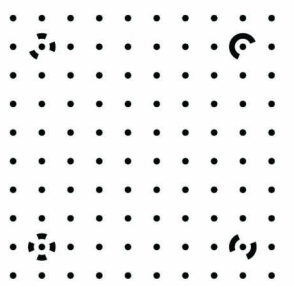


Figure 3: The Photomodeler calibration grid

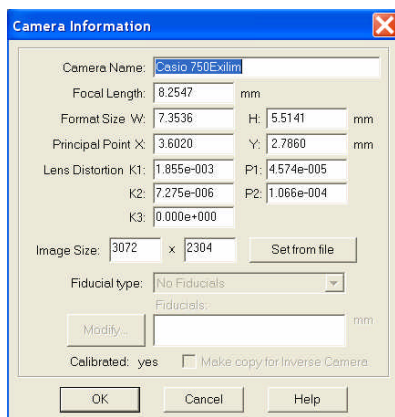


Figure 4: The camera calibration results

About 90 images out of the 300 collected were actually employed to create the 3D model. Given their high resolution (7 MB for each one), in order to limit the computational resources required for the photogrammetric data processing the work was subdivided in 4 different “projects” according to the following scheme: P1 for the north, east and west façades, P2 for the south façade, P3 for the great staircase and P4 to better model the portion of the front façade occluded by the columns, which could have prevented to correctly apply the textures. For each project, after a first minimum set of matching points has been manually selected among adjacent images and the corresponding relative orientation was computed, further geometric features such as points, lines, corner and cylinders were added to improve the level of detail of the resulting model. For each group of new elements added a global BA procedure was applied in order to recompute the relative orientation and to reduce the residual error. Then, the 4 projects were merged together by selecting a few points commonly distributed among the resulting 4 partial models and exploiting a proper tool provided by PhotoModeler. Finally, the scale factor and the absolute orientation of the global model were computed by using 3

GCPs measured with the Leica total station. Unfortunately the estimate of the transformation between the model reference frame and that defined by the total station survey (absolute reference frame) could not be improved as PhotoModeler allows to use only three GCPs at this step.

In order to achieve a more photorealistic product, the photogrammetric model was then enriched with the application of textures, which were manually selected by the user or automatically extracted by the software from the digital images according to the viewpoint and the presence/absence of obstacles or occlusions.

Figure 5 shows the recovered cameras poses while figure 6 shows a partial view of the whole photogrammetric model along with the applied textures. As can be seen from latter figure, some parts of the villa, such as the roof, the turrets, the statues and the staircase, could not be modeled. Indeed the position of these elements in the building's structure, the shape complexity and the collection of likely featureless images, which would have occurred in some cases (to meet the requirement about the side overlap), prevented the photogrammetric survey of such portions. Except for the roof, such objects were fully acquired with the laser scanner.

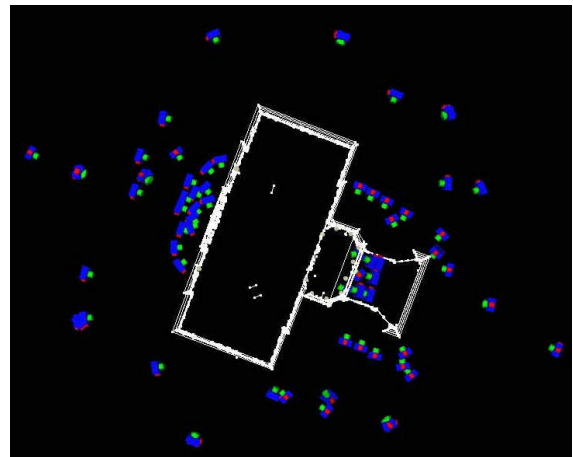


Figure 4: Recovered camera poses

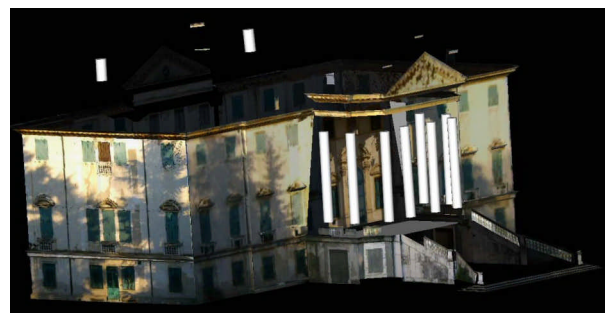


Figure 5: Side view of the photogrammetric model after image texturing.

4.2 3D Model from point clouds

To align and merge the range data to produce a polygonal model, Polyworks from InnovMetric was used. The registration of all scans was performed according to the following scheme: in the first step range data were aligned pair by pair, then a ICP-based global alignment was applied to the whole dataset. The latter procedure was required in order to distribute the residual registration error more

uniformly across the scans with respect to a simple pairwise approach, as described in several works (Besl et al., 1992; Bergevin et al. 1996; Pulli, 1999). At the end of this first processing stage, a residual error of 9 mm was obtained as RMS of the standard deviations of the image pair alignments computed by IMAlign.

Note that during the pairwise registration, in some cases the alignment algorithm failed to converge, providing a worse result than the initial pre-registration derived by the manual selection of a minimum set of matching points. This misalignment was due to position changes of some elements of the structure occurred between different scanning epochs. An example of this phenomenon is shown in figure 7 where it can be observed that the orientation of the window shutter (enclosed in the red circle) has changed between the two scans. However this issue could be successfully overcome exploiting a tool of IMAlign, by which selected elements of a range view can be temporarily ignored during the transformation parameter estimate and then re-used when such transformation is applied to the whole view.



Figure 7: Change of geometric position of some elements along the facades of the villa between different scan epochs led to a registration failure.

Once the scan registration was completed, in order to obtain a simplified 3D model which could be easily edited in Rhino software, a two-steps data reduction strategy was adopted. Firstly data redundancy was reduced exploiting some tools, provided by IMAlign module, that identify the best set of non-overlapping data points among a set of 3D images. Such method allows to reduce the memory usage and to speed up the meshing process. Then a further model simplification was applied in IMMerge, the Polyworks module where aligned point clouds are merged together into a global polygonal (triangulated) surface model. In this work, however, the meshing was applied just to a subset of the whole point cloud: the turrets, the great staircase and the statues of the main façade of Villa Giovanelli. Separated 3D models of these elements were achieved from laser scanning data as they represented a difficult task for the photogrammetric processing as mentioned in previous subsection. For the merging step, the user is requested to set few parameters, as shown in figure 8. In this case several attempts

were made in order to find the best compromise between model quality and number of triangles. At each trial the value of the reduction tolerance was changed while the sampling step remained fixed (1 cm). The former parameter allows to reduce the generated high-resolution polygonal mesh in such a way that triangles are preserved in presence of high surface curvature while they are reduced in the flat areas.

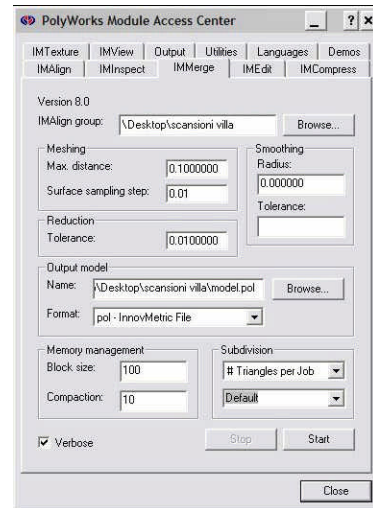


Figure 8: The IMMerge module

5. DATA FUSION

In most published works the concept of “integration” or “combination” of 3D models derived from photogrammetry and laser scanning is regarded basically in two ways: as texture mapping of the meshed TLS model or, conversely, as production of orthophotos using the aligned and triangulated point clouds as a DEM.

Here data fusion is aimed to create a unique 3D virtual representation where photogrammetric and laser scanning data are merged together so that the final product can be seamlessly explored. With this approach 3D modeling applied to Cultural Heritage can benefit of the use of both surveying techniques. For example, in the case of historical buildings, such as Villa Giovanelli, 3D information about enough regular portions of the structure can be derived from photogrammetry while more interesting architectural details and areas with higher surface curvature can be reconstructed from laser scanning data.

In order to be properly combined in one product, the two models had to be firstly related into a common reference frame, which in this case was defined by the total station survey. To this end the globally aligned and reduced point cloud was georeferenced, before the merging step, according to a method developed in a previous work (Guarnieri et al., 2004). Basically the transformation parameters were estimated through quaternion representation applied to a dataset composed by the 10 GCPs measured with the total station and corresponding points identified on the TLS-based 3D model. The whole photogrammetric model was then imported in Rhino as “.3dm” file, what allowed to keep the texture information provided by the high-resolution digital images, while the separated laser scanning models were imported as “.dwg” files. The unified model was edited in order to create or reconstruct those parts of the building which could not be

properly imaged or surveyed with the laser scanner given their geometry and position with respect to the data capture stations. Model editing concerned the generation of the roof, reconstruction of the turrets and the adding of other minor elements, such as two chimneys in venetian style located in the north wall of the villa (see fig. 2).

The roof was created by attaching different geometric primitives (planes and triangles) to points and lines of the photogrammetric model. At this stage the exact shaping of added elements was accomplished by using a few images taken from the turrets. An inclination of 30° was then applied to the roof pitches.

In order to not alter the existing data, derived from the laser scanning model, the turrets were reconstructed by simply extruding the profiles resulted from interpolation of the laser points, as shown in figure 9. Here, in the upper left view it can be recognize both the source data points (in black) and the interpolated lines (light red). In the upper right panel it is shown a close-up view of the result of the extrusion: the roof of the turrets has been also edited with specific tools provided by Rhino. Then exploiting the information from collected digital images and solid primitives, such as cones, cubes and cylinders, the chimneys and other minor architectural details laying on the upper part of the north façade were reconstructed. A set of wireframe views of the final model is presented in figure 10.

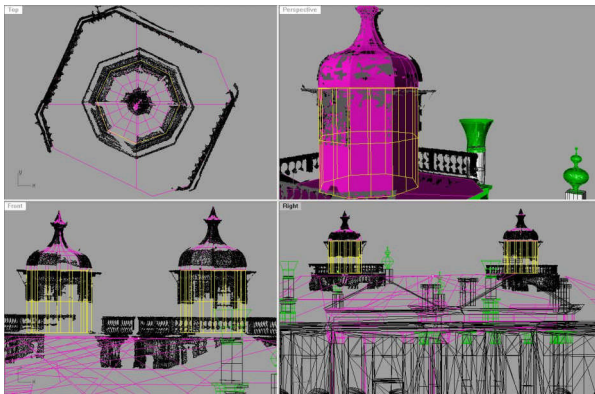


Figure 9: Extrusion of the right turret

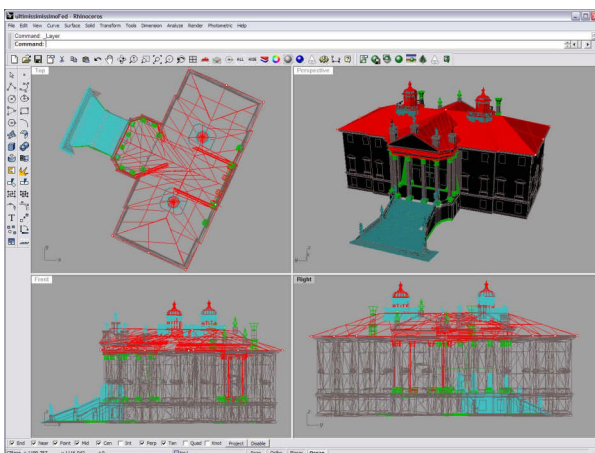


Figure 10: Wireframe views of the complete model in Rhino

As a last step of the data fusion, the 3D model was rendered by using the textures already existing and associated to the photogrammetric component and creating new ones for the laser scanner data and added elements by means of a material library available in Rhino.

Two examples of the unified and textured 3D model of Villa Giovannelli are presented in figure 11 and 12, showing respectively the south-east and north-west view of the villa.

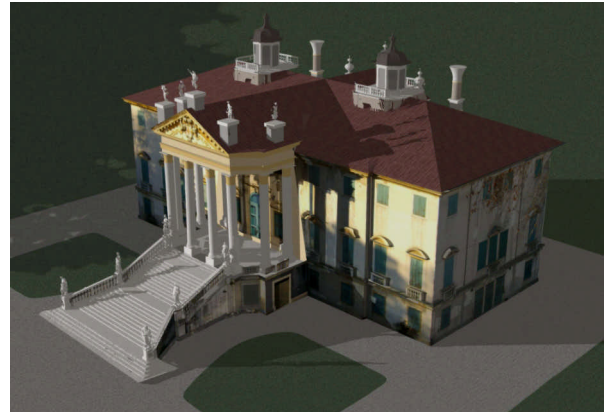


Figure 11: South-east view of the unified 3D model



Figure 12: North-west view of the unified 3D model

6. CONCLUSIONS

In this paper the generation of a 3D model of an historical building based on the combination of two different surveying techniques has been presented. The main goal of the work was to merge in a unique product data derived from close-range photogrammetry and from terrestrial laser scanning in such a way that the final model could be seamlessly explored. A proper modeling procedure was developed in order to better exploit the surveying capabilities provided by both techniques: the main structure of the building (i.e. outside facades and the porch) was determined by image-based method while fine details (statues, turrets and the great staircase) were modeled by range data. Given the satisfactory results achieved with the adopted hybrid approach, this paper further demonstrates that these two technologies, when properly employed, can well supplement each other in creating high-quality 3D recordings and presentations.

However, open issues mainly related to the modeling step need to be addressed in the future. For instance, the combination of data acquired with independent measurement methods highlighted some difficulties of communication between different processing softwares: in most cases there is no common data format which allows the user to keep all the information when migrating the data. File format, such as DXF, DWG and VRML, are often used for this purpose but they reveal to be inadequate when dealing with high resolution polygonized models as those derived from laser scanning data.

Furthermore, model resolution plays a great role when a 3D model generated from TLS data has to be edited in software like Rhinoceros or 3D Studio Max, which are still not well optimized to process very dense datasets. Minimum number of triangles per file to be imported and/or bad memory management represent typical limits which prevent the user to work more easily and faster. Such limits can be overcome by applying a mesh simplification procedure, however with this approach data are discarded and part of the original information is lost.

Given the capability to create stunning presentations, the use of this kind of softwares is becoming more and more a fundamental component of the 3D modeling pipeline, therefore it is advisable that in the next future significative improvements will be carried out even in this sector.

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