MULTIRRESOLUTION SURVEYING OF COMPLEX FAÇADES: A COMPARATIVE ANALYSIS BETWEEN DIGITAL PHOTOGRAMMETRY AND 3D LASER SCANNING

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ABSTRACT

Multi-resolution surveying is a topic with increasing interest for information management and visualization of Cultural Heritage. Highly ornamented façades provide a challenge for testing integration of techniques to different resolutions. In this work we develop two strategies based on high resolution digital photogrammetry and 3D laser scanning for architectural and sculptural surveying of complex façades of highly ornamented religious buildings including late gothic and early renaissance elements. We review some recent work related with the façade surveying of several buildings (San Gregorio, San Pablo, Santa María del Campo) with gothic and renaissance elements. All of them present a very high complexity from the ornamental viewpoint. Traditional stereo restitution has been applied for architectural and sculptural surveying but with a very high human work cost and high expertise. A substantial reduction is achieved with the application of laser scanning. Image-based models of the façade of highly ornamented façades allow to identify structural elements, and decompose it in smaller pieces for simplifying the computer management. In particular, structural elements provide a regional segmentation based on high resolution image-range photogrammetry which can be lifted to scan files. In some cases, range-scanning approach is based on Minolta 910 for very close range and, more generally, with ILRIS 3d (Optech) for global scans. Fusion of local and global geometric information can be performed even under very bad illumination conditions. The interplay between ornamental and structural aspects improves the understanding of the building, and contributes in an essential way to the geometric modelling, computer management and architectural interpretation of other similar buildings presenting a similar high complexity for ornamental details.

1. INTRODUCTION

Multirresolution surveying is a technique able of displaying and editing with different levels of detail 2d or 3d information on a geometric support. Very large amount of data requires optimal procedures for subdivision, clustering and management of the resulting graphical information. Geometric optimisation is supported on additional structures (meshes, textured surfaces, e.g.) which must preserve the “meaningful data” of the shape. Meaningfulness depends on the chosen resolution. Computational Geometry [Berg et al, 2000] provides piecewise linear models (PL in the successive), and algorithms for contracting/expanding geometric information for digital inputs arising from high resolution views and laser scan files and their superimposed primitives.

Three-dimensional scanning devices are contributing to a substantial improvement in Cultural Heritage surveying. Late nineties and the first years of the 21st century have been focused towards the exploration and application of information technologies towards surveying, with different requirements involving accuracy, robustness, flexibility or interaction capability for generated 3D models. The increasing performance of 3d lasers and dedicated software provide information for surveying based on discrete dense information about objects. After a first exploratory stage, limitations of each image- and range-based methodology are identified. Currently, a larger effort is focused towards the development of hybrid approaches able of improving the contribution of each approach. It is commonly acknowledged that hybrid and interactive or semiautomatic methods are need for almost every problem in surveying. Hybrid methods propose the fusion of information arising from different sensors for exploiting the advantages of photogrammetric recording, multiple views and range 3D laser devices. After recording, processing and matching scans, a 3D digital model is generated with several levels of detail.

An on-line accurate visualization of volumes linked to buildings requires to simplify range-scanning PL-models (meshes and textured surfaces). The cost of the simplification is the lost of details in final rendering. A high resolution display is sometimes incompatible with facilities for remote access or depend on the visualization capability of browsers. Thus, it is necessary to improve the memory management for making compatible the information in successive layers depending on the information complexity and the capability of browsers for advanced visualization.

The diversity of sources and objects increase the complexity for the computer management of hybrid solutions, and make difficult to compare results which are obtained with different methodologies. Indeed, even when clouds of points are projected on planar views, different densities require to implement a) resampling procedures for comparing inputs, with their corresponding algorithms for grouping and reduction (vertices clustering and collapsing edges), and b) to adapt usual contours extractions and drawing tools to the discrete nature of 3d inputs. To improve the information management contained in dense clouds of points, several software tools have been developed to recover original information contained in scans or views, and to avoid distortions linked to superimposed structures. Furthermore, it is necessary to exploit radiometric information contained in discrete clouds of points for extracting 3d space contours or curved surfaces. Finally, it is desirable to develop software tools for information fusion of scans and high resolution views.

Figure 1: A corner of the Palacio de Santa Cruz to be fitted on the 3d scanned model captured with Ilris 3d

A critical issue appears when façades present a very rich ornamentation or sculptures. Traditional survey based in a small number of views leaves a very large number of empty zones, or it presents a very high computational cost. Anyway, there is still a very large number of occluded zones to be filled. To solve this problem, 2d image-ranging and 3d range-scanning approaches have been developed along last years.

Typical constraints for volumetric reconstruction of complex façades are linked to precision and edition possibilities for professional requirements (relative to ornamental elements and sculptures) and facilities for display and navigation. A balance between both typical constraints is very difficult to find. Thus, in this work a two layer approach is developed with two different resolutions for different purposes. In both cases, we have applied a range-scanning approach based in triangulation (Minolta 910) and time-of-flight (Ilris 3d, Optech) laser scans for small and mid range.

Organization of the paper: Section 2 reviews some hybrid approaches related with ours. Next, we sketch some of the computer tools for regional segmentation in image and scans, and we display how to manage the original discrete information and its export to CAD files. Image-based and range-scanning approaches are developed in section 4 with a restitution based in photogrammetric pairs for a pilot zone. Section 5 is devoted to the fusion of metric information arising from scanning files and rectified affine information arising from photogrammetric surveying, with different resolution levels linked to visualization tasks. Finally, some conclusions are presented including a comparison of results arising from both methodologies on a common 3d support.

2. DIGITAL INFORMATION SYSTEMS FOR SURVEYING FAÇADES

Conservation and restoration policies of Cultural Heritage requires a careful planning and the selection of a methodology understandable in the fieldwork by non-experts, which can be easily incorporated to a global digital information system of each building. A Digital Information System (DIS, in the successive) as been designed for evaluating, covering and tracking incidences or pathologies along conservation and restoration tasks. The DIS has been developed with two levels of detail for making more visible the evaluation of local damage, assist the planning of restoration interventions and to evaluate the current state of building.

Figure 2: A global DIS card for restoration tasks in Cultural Heritage (façade, San Gregorio, Valladolid)

Far from being a waste or repository of information, the digital information system (DIS) give tools to improve the knowledge of building and to correct incidences along a large time period. For achieving this goal a collection of cards is designed which allow to identify incidences and pathologies in worksites, and to make easier a recording and periodic tracking of pilot zones with high risk or identified damages.

Figure 3: A local DIS card for map of lesions superimposed to a local restitution of sculptures.

Two important areas which contribute to the computer management of DIS are Close-range Photogrammetry and Computer Vision. Computer Vision develops models and algorithms based in different filtering and grouping processes for 1d primitives (edges, contours) and 2d primitives (regions, e.g.) which can be lifted to 3d models by means of some reconstruction process [Hartley and Zisserman, 2000]. Sampled points in high resolution views gives a dense information which can be compared with dense information arising from another sensors (3d laser, e.g.). Dense 2d information can be taken with a hand-held digital video camera. The existence of very small baseline between consecutive frames allows to generate high resolution synthetic views from video sequence. In their pioneering work [Pollefeys. Koch and Van Gool, 1998] present very impressive results relative to a visualization of a metric reconstruction for the façade of an Indian temple, from a textured mapped 3D model using an area based stereo algorithm. Thanks a careful planning of different phases, their approach provides a 3d VRML model which minimizes the number of occlusions.

Figure 4: Examples of stereo pairs of partial and global views of the Façade of the National Museum of Sculpture (San Gregorio, Valladolid, Spain)

Traditional image-based photogrammetry developed on high resolution views of complex façades are based in stereo pairs. They allow to obtain rectified models according to a locally dominant plane.

Figure 5: Manual restitution obtained from stereo pairs of a detail of San Gregorio (Valladolid)

An advantage of Digital Information Systems for restoration and conservation tasks is the following: Cards corresponding to plane rectified views of the façade are self-explicative; they do not need additional viewer, are easily understood for the fieldwork and can be immediately incorporated to the data structure of the building.
Export of rectified views to CAD (by means of a manual cut-and-patch technique), allow draw directly on the 2d file with very precise information. Nevertheless, the high quality results, this task is very consuming in human work. Currently, we are still some far for providing software tools based in split-and-merge algorithms [Berg et al, 2000] for identifying and generating polygonal 3d chains fitted to each individual sculpture in an automatic way. In the meantime, we have adopted a hybrid strategy which takes advantage of performance of laser-scanning approach for generating 3d models. Partial export of 3d files to CAD provides a support where rectified views and very precise drawing can be superimposed (Figure 6).

Figure 6: Front-elevation on a rectified view of a Renaissance tower of Santa Mª del Campo (Burgos)

This method is still very time consuming. Direct export to CAD generates a file with 1.5 times the original txt volume, which allows to draw directly on the 3d support. Automatic extraction and grouping of fat contours has not still enough quality, and thinning and reprojection algorithms are currently applied to the 3d support. Thus, a combination of highly specialized manual work on a semi-automatically extracted digital support is need for satisfying professional requirements in architectural surveying.
Ortophotos give an unfolding of objects on a piecewise linear or developable model. The resulting unfolding is very useful for Computer Graphics applications, because it allows to navigate around the whole object without holes corresponding to orthogonal views from each viewpoint. Thus, in this work, we have developed an approach based in front- elevation-views. The resulting rectified views can be re-projected on 3d models captured with time-of-flight laser scans, but some problems relative to the automatic correction of wrong striated profiles persist in interactive navigation.

Figure 7: Front-elevation view of the tower of NªSª de la Asunción (Santa María del Campo, Burgos)

Small distortions near to the tangency locus of projections are present for any planar representation. To avoid them, a traditional approach in Computer Graphics is performed by constructing developable surfaces by hand. Nevertheless very good results for high resolution rendering, this solution is very expensive in human cost. A semi-automatic generation of ortophotos from projective 3d reconstruction in Computer Vision by using epipolar geometry. This solution fulfils high resolution professional requirements: metric information can be extracted and textured maps provide a photorrealistic view. However, the development of high level software tools for Projective Reconstruction from several views according to [Hartley and Zisserman, 2000] presents a high complexity level. As conclusion, Computer Vision and Computer Graphics approaches require a high expertise for edition and information management from user's side.

3. LASER SCANNING FOR GLOBAL MODELS

Laser-based approach gives directly metric information relative to the Euclidean Reconstruction in Computer Vision and provides dense information relative to 3d geometry and radiometric properties, with a lower human cost.

Figure 8: Laser scanning with Ilris 3D (Optech) in Santa María del Campo (Burgos)

Laser-based range scanning reduces time in field, evaluates volumes in an accurate way and reduces surveying costs, including georeferencing aspects. Usual 3d reconstruction in Computer Vision is based on several views. Stereo vision diminishes the number and size of partial occlusions, avoids ambiguity and reinforces the coherence of local radiometric information. Meaningful metric information can be extracted in an automatic way from a scan), but to avoid occlusions or shadows linked to the projecting cone of scanning, it is necessary scanning from different poses. Inversely, too redundant information generates also problems which must be identified and eliminated, by avoiding multipath or mixed-pixel effects. Hence, in this case it is necessary to develop several simplification and optimisation procedures for clouds of 3d points.

Figure 9: A global 3d model of the tower of Santa Maria del Campo (Burgos, Spain)

Laser-based multirresolution approaches are based on simplification of 3d clouds and their superimposed structures (meshes, textured surfaces). A blind selection of the original cloud of points could delete meaningful elements. Thus, a selective decimation is necessary to achieve optimal results. There are several geometric optimisation criteria [Hinker and Hansen, 1993]. Geometric optimisation consists of a reduction of polygons and surfaces which preserves a faithful shape representation. Some optimisation criteria are labelled as hierarchical methods, re-tiling or "smart" decimation, e.g.. Most of them use clustering of vertices or collapsing/swapping edges algorithms [Hoppe, 1996]. A smart reduction adapted to curvature variations is displayed next.

Figure 10: A view of discrete cloud of points for the 3d global model of the façade of San Pablo

Furthermore, a walkthrough is generated from Polyworks, which allows a re-display of a static scene from a moving viewpoint. After merging several scans, and cleaning spurious elements, we obtain a global discrete model (clouds of points) for isolated buildings or complex façades. From the global discrete model, the application of dedicated software provides meshed and textured surfaces with their corresponding walkthroughs.

4. FUSION OF INFORMATION ON 3D MODELS

A connection of range scanning with Computer Vision approaches is performed by using similarity transformations, a type of affine transformations. After [Pollefeys, Koch and Van Gool, 1998], to avoid skew in 3d visualization it suffices to restrict to similarity transformations. Views generated with similarity transformations are patched on 3d models arising from scanning. Merging process between 2d views and 3d scans is hand performed. Visualization of automatic merging requires to construct a common spatial reference and to integrate software tools for the management of 6d files relative to the same object with different density in the uncalibrated case (parameters of internal camera are unknown, zooms for external camera are allowed). To solve it, we are developing a software platform for the automatic merging of high resolution 2d views and 3d scanning.

In Computer Graphics, a realistic complete model can be performed in terms of piecewise developable surfaces to prevent abrupt changes in concave/convex regions. Usual method is based on re-projection on piecewise-linear or –cylindrical models. Its computer management presents a very high complexity, which is increased in complex façades due to the necessity of implementing a management of protrusions and extrusions [Martinez et al, 2005]. Furthermore in complex façades it is not possible to locate the laser device with the best orientation with respect to the objects to be scanned. It is necessary to incorporate high resolution views which must be merged on a 3d model generated from 3d Reconstruction in Computer Vision and some kind of interactive Computer Graphics based approach.

All these arguments arising from the high expertise required for the application of computer vision tools and the additional high human cost in computer graphics, justify our reduction to photo-frontal-views instead of using rectified views.

5. SOME EXAMPLES AND DISCUSSION

In this section, we review some recent surveying work focused towards conservation and restoration tasks in three buildings constructed along late 15th and early 16th centuries. To fix ideas, we have concentrated the attention in the façade of San Pablo (Valladolid), which displays a very large amount of gothic high-reliefs in the lower-part of the façade and renaissance style ornamentation in the upper-half of the façade. This hybrid character requires an adaptive geometric model for a faithful representation of the volumetric segmentation, having in account the space distribution of ornamentation.
The original gothic building was strongly modified between 15th and 16th centuries to accommodate the large expansion due to the presence of the court in Valladolid, as the capital of Spain. Historical studies allow imagine an ideal reconstruction of the original state of the façade before the current state.

Figure 11: An ideal digital reconstruction of the façade of San Pablo (Valladolid, Spain) before modifications of late 15th century and the current state

Two rectified mosaics captured with different resolution are generated from more than ten and forty views, respectively. In this way, we have two high-resolution support for 2d model of the façade that can be reprojected on a 3d model. The next figure displays the meshed model of the façade of San Pablo with almost 2 million points, almost 3.5 million of triangles, and a scaling factor of 1:1.000.000. Some meaningful data for scanning of the façade of San Pablo are the following ones: 3212440 shots, file with 2086 rows and 1540 columns, Shot type: I3D, pattern Type: Step Stare, Start position: Lower left, average range: 69.96 m, X/Y spot spacing (mm/integer: 20mm(/11), with horizontal orientation.

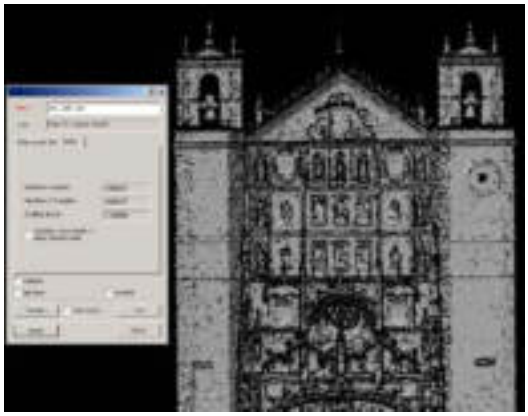

Figure 12: Mesh of the façade of San Pablo

A superposition of the façade to low resolution on the plane projection of the cloud of points is displayed in [Martinez et al, 2005].

6. CONCLUSIONS AND FUTURE WORK

Several strategies have been developed in this work for surveying complex façades of several Spanish buildings constructed along the late 15th century and the early 16th century. Complexity of gothic and renaissance styles imposes the necessity of working with different resolution levels. The fusion of image ranging and laser scanning approaches provides a flexible semi-automatic solution with different levels of resolution simplifying the hard photogrammetric work and increasing the productivity with acceptable levels of accuracy for surveying of Cultural Heritage of building with rich ornamentation.

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