MULTISCALE THREE-DIMENSIONAL SURVEYING FOR CONSERVATION TASKS: A PILOT CASE FOR THE FUSION OF RANGE-SCANNING ON ARCHAEOLOGICAL SITES

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ABSTRACT

Integration of 3D data in digital photogrammetry is a challenge in solid object modelling and visualization of large scale scenes. Geometric primitives are need for a robust management of large reduced scenes, and an accurate visualization based on dense information is required for specific complex regions. Two complementary strategies for the fusion of high resolution digital photogrammetry and laser scan are developed in this paper. The first one is oriented towards the generation of a 3D geometric model based on a dense depth map linked to a large number of images. The second one is oriented towards the management of the whole 3D scene with an intelligent decreasing of the file size adapted to expected primitives. Our contribution is linked to the automatic identification of geometric primitives, adaptation of warping techniques and the development of a voxelization with two levels of detail. On the way, we develop some interfaces for the management of 3D information from CAD models and the connection between unordered clouds of points and GIS data, relative to the environment with common geometric CAD primitives supported on 2D and 3D information. We illustrate this hybrid approach with the surveying of a Spanish medieval castle (Trigueros del Valle, Valladolid) and a small chapel of the first gothic style in the monastere of Santa Maria de Valbuena (Valladolid), including a fusion of discrete clouds of points captured with triangulation and time-of-flight 3d lasers.

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1. INTRODUCTION

The fusion of information in a common 3d framework is a challenge for the application of information technologies in surveying Cultural Heritage. The combination of topographic networks, ortophotos and laser-scans poses methodological and functional problems for planning, capturing and processing information to achieve a surveying with professional requirements. Inputs from laser scans are given by unordered clouds of 3d points, whereas inputs from high resolution views are given by 2d pixels on the camera plane. High resolution image-based approaches are focused towards matching 2d views by means of some reconstruction method. In digital photogrammetry, image-based approaches use colour properties for surfaces and bundles adjustment for geometric primitives; computer vision provides software tools for assisting the reconstruction of 3D scenes [Hartley and Zisserman, 2000]. Fusion of image-ranging approaches to Archaeological surveying has received attention in a high number of recent works [Guidi et al 2003]. The adaptation of dense reconstruction methodology to large datasets arising from laser scans is an on-going research. In our case we work directly on dense clouds arising from very large laser scanning files, with software tools for superimposing geometric structures (meshes, textures, PL or PS-surfaces) to clouds of points.
Surveying and visualization of large urban environments or complex archaeological sites are typical problems where a multirresolution approach is required; a large number of contributions can be found in recent proceedings of CIPA Symposia, and ISPRS Workshops, focused towards surveying of Architectural and Archaeological Cultural Heritage. Large scale GIS applications use geometric meshing for multiscale rendering. Triangular Irregular Networks (TINs) provide a flexible solution for multirresolution depending on the chosen scale reduction [Berg et al, 2000]. However, large datasets arising from laser scans requires the development of processing tools for subdivision and re-grouping in 3d modelling. Both processes modify substantially the superimposed meshed structures. Smart meshing reduction depends on a hierarchy of primitives from the coarsest level (topological, geometric) to the finest one (architectural, topographic). On the other hand, direct CAD modelling of urban environments is benefited from the accurate and dense information capture arising from laser scans [Sanjose et al, 2005]. The combination of global flexibility of textured models with local accuracy of geometric primitives requires the development of specific processing and visualization software tools for satisfying flexibility of TINs with robustness/accuracy of geometric primitives. To satisfy both requirements, it is necessary to develop more flexible software tools for 1) a coherent interpolation between identified primitives, and 2) a compatible adaptability to adjacency conditions for GIS applications.
There are mid-level computer vision software tools for the scene interpretation (perspective models) in terms of piecewise-linear or piecewise-smooth superimposed structures (normal vectors to triangles, contours extraction, correspondingly). The interpretation in terms of mid-level primitives requires a post-processing and a high human/computational cost. It is commonly acknowledged that it would be desirable to obtain such information from dense maps, in a more direct way. Some work has been performed along last years for obtaining 3D information from dense depth maps. Information management by means of CAD software tools requires the design and implementation of algorithms for subdividing clouds of points according to their volumetric significance. In this work, we develop an approach including volumetric subdivisions based in grouping of tetrahedral decompositions fulfilling conditions similar to Delaunay. Computer Graphics tools have been applied for rendering large fortified environments from high resolution views [Bacigalupo and Cesari, 2003]. Currently, we develop interfaces for the management of 3d information with different levels of detail, depending on the urban surveying or archaeological visualization requirements for the insertion of Computer Graphics tools in large scanned environments.
To achieve this goal, we have developed a hybrid approach with two resolution levels which are labelled as coarse and fine,

respectively, involving both information processing and 3D model generation. Roughly speaking, coarse level would correspond to piecewise-linear robust model with a low number of meaningful control points, whereas fine level would correspond to piecewise-smooth accurate model with selective dense clouds of points. The interplay between both of them is performed in terms of cascading algorithms depending on the adaptive behaviour to spatial complexity of captured regions. A 3d visualization is also benefited from the two-level approach: coarse piecewise-linear model is the support for interactive display, which is extended to a fine piecewise-smooth model.
Methodology and obtained results are illustrated with the surveying of a late Spanish medieval farm-castle in Trigueros del Valle (Valladolid, Spain), currently in excavation and conservation tasks. To achieve it, we have used a laser device *ILRIS 3d* (Optech). Fusion of information arising from large ranging scanning (arising from *ILRIS 3d*) and short-range (arising from Minolta 910) is performed on another example corresponding to the Capilla de San Pedro (Monasterio de Valbuena, Valladolid, Spain). This small chapel of the early gothic style, has been in excavated along the first months of 2005; it presents several tombs, which have been scanned to high resolution. A more complete surveying of underground castle dependences is still standing. Main software tools used are Polyworks for processing discrete clouds of 3d points, and AutoCAD 15 for managing architectural primitives arising from the exported subclouds.
The paper is organized as follows: Section 2 is devoted to explain some aspects of buildings which are relevant for information capture depending on the chosen framework and the planned application (archaeological or architectural surveying). Next, an outline of algorithms for the volumetric decomposition based in tetrahedra is provided. The fourth section displays the results obtained from the application of the performed implementation of algorithms. A comparison of obtained results following different methodologies is presented and discussed in section 5. An evaluation of results, conclusions and some remarks about next future work are given in the final section.

2. CAPTURE

A specific methodology for archaeological surveying has been developed along the last years of 20th century with usual photogrammetric resources [Miyatsuka et al, 1996], and including laser scanning contributions from the early years of 21st century [Ioannidis et al, 2000], [Agnello et al, 2003], [Kadobayashi et al, 2003], [Finat et al, 2005], between others. So, we restrict ourselves to some specific questions relative to surveying of an archaeological site currently in excavation.
Military Cultural Heritage poses some specific problems for surveying linked to different layers, sometimes partially hidden, which are difficult of identifying. The castle of Trigueros del Valle was built along the 14th century with important modifications along 15th and 16th centuries. It has a typical external structure including cylindrical towers along the fortified perimeter, two main rectangular towers as residences for owners and soldiers.

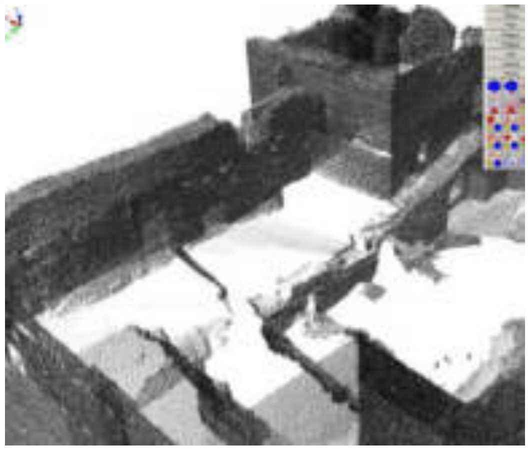

Figure 1: An internal 3d scan with the court yard and the ruined tower of the castle of Trigueros del Valle

The internal structure corresponds to an untypical farm-castle, with a large number of semi-subterranean dependences organized around an internal court yard. Uncontrolled excavations or partial demolitions around the underground dependences are in the issue of the current bad state of the whole building. To prevent the ruin of both rectangular towers several actuations on the most important tower have been performed with severe restorations which have avoided its total ruin. Deviations with respect to the vertical line of the second tower are important, also. Archaeological vestiges are ubiquitous inside the perimeter. The current architectural and archaeological surveying of the whole building, far from being simply a repository, contributes in a substantial way to the knowledge and understanding of the castle and landscape inventorying,

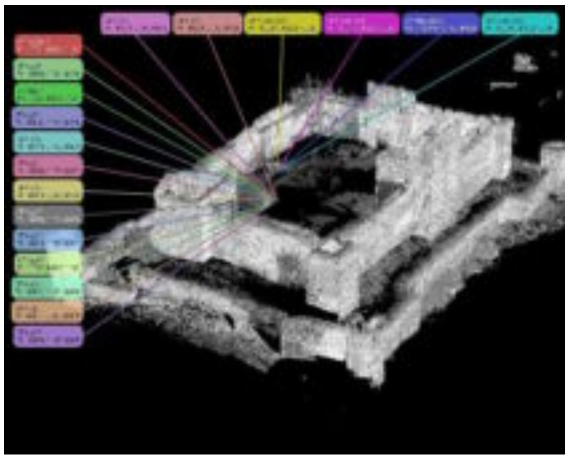

Figure 2: Map with localizations of scans for the castle of Trigueros del Valle

Data collection for the medieval castle of Trigueros del Valle is performed with the laser scan Ilris 3D (Optech) with a spot of between 5cm and 20 cm and a semi-metric calibrated camera with a scale near to 1:80 mounted on the same tripod along the capture for minimizing errors linked to parallax effects in merging views and scans. Each laser scanning provides at least thirty and fifty thousand points, and it is performed to have about an overlapping of at least 20% between adjacent scans. Scanner localizations and capture are limited by consolidation work.
A key fact for merging is the right *identification of homologue*

elements in different views or scans. Algorithms use geometrical information about selected points or, alternately, about superimposed geometric primitives such as meshes for bottom-up approaches or perspective models for top-down approaches. Merging partial clouds is performed by selecting manually a number of homologue elements in general position.

Figure 3: A global view of the textured 3d model

3. ALGORITHMS DESIGN

Architectural surveying needs robust software tools for selective refinement and grouping around meaningful primitives in archaeological or urban surveying. Usual reduction techniques for dense information work on superimposed structures (meshes, textured surfaces) resulting from the application of laser processing, instead of acting directly on clouds of points.

A crucial difference between the management of digital clouds of points in algorithms design is linked to 1) *topological* (proximity), 2) *algebraic* (local symmetry) or 3) *geometric notions (*fitting to simple geometric primitives). For example, 1) laser scanning software tools operate on unordered points which can be locally reordered, by applying search criteria around first and second levels of proximity; 2) computer vision software tools operate by weighted or probabilistic averaging around continuities or discontinuities, by extending or breaking local symmetries to different levels (from pixel to structural elements in perspective models); 3) CAD models privilege some standard geometric primitives for linking data to rendered global objects and to select optimal geometric primitives to discrete clouds of 3d points.

Figure 4: A partial view of walls of the castle with well defined depth planes delimiting spaces for different uses

For 3d rigid scene a minimal choice is given by four non-coplanar points which can be interpreted as an affine reference tetrahedral. In perspective models for 2D views, all reference tetrahedrals are equivalent between them through a projective transformation; this well-known fact justifies the choice of a tetrahedral containing at least three non-aligned vanishing points of each view as vertices. Alternately, if we use information about normal vectors to faces lying on meshes, then one must take care about changes in orientation of homologue faces; in particular, opposite viewpoints induce opposite relative orientations for the normal vector to the same face, which could give a lack of coherence for global matching. To avoid this inconvenient, we have developed a local matching strategy.

The goal of our *volumetric propagation algorithms* in a 3d model of the scene is the fusion of 2d and 3d information, by imposing constraints linked to the automatic identification of volumetric primitives and propagation along their boundaries. Information fusion has been developed by other experts (see [Kampel, Sablatnig, and Tosovic, 2002] for a related approach). In our case, we propose a generation of *Delaunay tetrahedralization* similar to the standard in Computational Geometry [Berg et al, 2000], but whose facets are adapted to the boundaries of architectural objects. It is performed in two steps: 1) towards the interior of the big tetrahedral of reference ***T***, and 2) towards the exterior of ***T***. Eventually, a larger number of points could be required, depending on the scene complexity. Main problems concern to the computer management of collapsing/swapping facets on 3d volumetric simplifications preserving the global topology of visible objects in the scene. To solve them, we develop a geometric search guided by trees with recurrent subdivision and grouping. Collapsing/swapping processes are allowed in trees, but without breaking the graph connectivity, as it is usual in alpha-shapes.

To avoid an excessive amount of tetrahedral small pieces in recursive subdivisions, partial grouping in intermediate cubes is developed. The obvious extension to 3d case of flip-flop exchange of diagonals in quadrilaterals provides a fitting to the simple volumetry. Indeed, every parallelepiped decomposes in six 3d simplices. Opposite faces have two pairs of homologue diagonals which can be exchanged. Exchange of diagonals in opposite sides is extended to an exchange of diagonal planes depending on the relative orientation of identified facets, and consequently of triangular prisms. In more complex models with variable curvature [Martinez et al 2005], 3d-simplices for each prismatic component are fitted depending on isosurfaces.

A coarse model for volumetric propagation is developed from an initial small tetrahedral, the only which contains the origin. A tetrahedral is adjacent to the initial if they have a triangular facet in common. Proximity levels are recursively constructed from the initial tetrahedral following a bottom-up approach. An adjacent tetrahedral is aggregated to the initial if their facets do not cross the identified geometric primitives linked to simplest constraints for (coplanar, co-cylindrical) facets. In this case, common facets are deleted. Otherwise, query process jumps to the next node linked to the next adjacent facet of positively oriented tetrahedral. The procedure stops when the boundary a “typical volume” (plane, cylinder, in our case) is filled. If the list of typical volumes is empty, then a query procedure is introduced for identifying coplanar or co-cylindrical facets. After merging several scan files, the volumetric propagation can be extended to the set of central nodes (one for each scan), and to apply a competitive/cooperative algorithm strategy. A RANSAC type extension of volumetric propagation based in a sparse subcloud is currently under development. Goal of volumetric propagation algorithms is the recovery of solid structural elements corresponding to walls with architectural information by minimizing the computational cost.

An optimal search between near vertices under a proximity threshold is performed following a min-max optimization algorithm. An optimal volumetric decomposition is achieved which minimizes the volume and maximizes the region determined by the trihedral angle generated by three edges. In this way, for each pre-selected vertex, the search is performed between the three nearest vertices belonging to the circumscribed empty sphere through the four non-coplanar vertices, and it is propagated for each triplet of vertices lying on a face of each small tetrahedral. An empty sphere is a sphere which does not contain another vertex inside, besides the four initial vertices. The resulting tree representing the aggregation process is strongly not balanced, and query processes could be very expensive. To achieve a balanced tree, it is necessary a) to delete almost flat tetrahedrals, and b) to merge tetrahedrals with common facets belonging to the same basic volumetric primitive (plane, cylinder, in our case). A tetrahedral is almost flat if the differences between normal vectors to three faces are lesser than a prefixed threshold. If the chosen vertices generate a reference tetrahedral "almost flat", then the propagation will give errors in determining an optimal tetrahedralization, and the tetrahedral will be discarded. Similarly, if some edge has length larger than expected, then the tetrahedral is not generated. In particular, for each scan there will be different connected components.

An on-going research is focused towards an individuation of volumetric primitives with a very low number of meaningful points which can be managed by advanced computer graphics tools. A first export of ASCII file to *.dxf format multiplies by three the original volume. A second export to *.dwg fomat reduces to the half the volume of *.dxf format. Thus, it is necessary a preliminary reduction of large dataset which preserves the basic geometric primitives.

4. INFORMATION PROCESSING

In this section, we explain a volumetric segmentation in scans, and how to manage the original merged data and its export to CAD files. We have followed a strategy which consists of going from the most general models to the more detailed ones. A general scanning of Trigueros del Valle has been performed with the *ILRIS 3d* (Optech) for the understanding of the current situation.

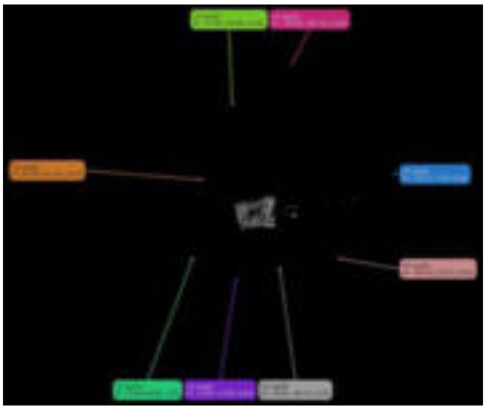

Figure 5: Landscape inventorying of the village and castle of Trigueros del Valle

In absence of previously determined depth planes, subsets of clouds of points can be manually selected in closed regions and simple geometric primitives can be fitted to subsets of discrete clouds of 3d points.

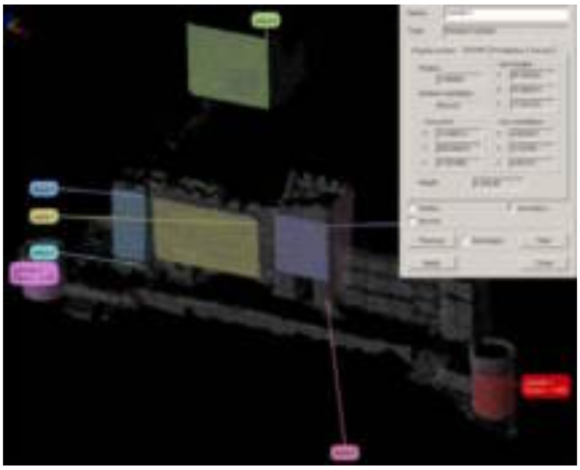

Figure 6: Adjustment of cloud of points to selected geometric primitives

Traditional architectural surveying is based on planar information linked to frontal views, plants and sections. From the 3d laser scans it is possible to obtain all of them with an error lesser at most of 5 cm for the whole global model. A very simple program allows the export to a CAD file, where one can apply usual graphic modelling tools. The small increase (factor of 1.5) of file size is compensated with the dramatic reduction linked to the extracted contours.

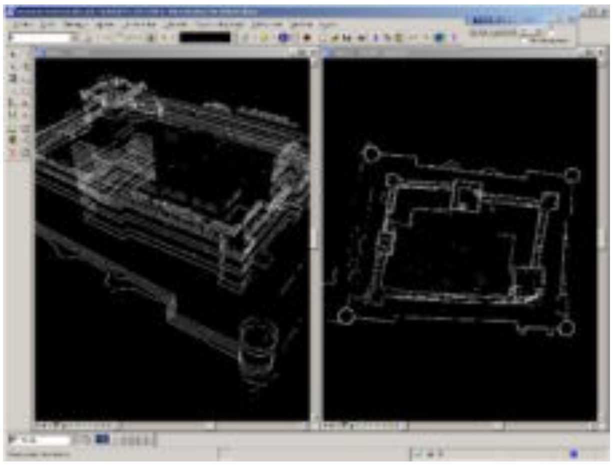

Figure 7: A map of sections with constant step and its conversion in a CAD file

Resulting 3d model provides a very precise representation with a low cost and high productivity in regard to other traditional photogrammetric surveying techniques. Furthermore, it provides a 3d support for the fusion of high resolution views [Martinez et al, 2005], and for applying Virtual Reality tools for more realistic representations fulfilling surveying requirements [Finat et al, 2005].

5. COMPARISON AND DISCUSSION

Mosaic generated from laser scanning provides an accurate dense support for surveying. Photogrammetric recordings and processing is considerably simpler when it is superimposed to 3dmodel generated from laser scanning, instead of applying usual photogrammetric or Computer Vision methods, only. Furthermore, after merging scans density of laser scanning files

is often larger than density for high resolution views. Accuracy of laser scan *Ilris 3d (Optech)* is lesser than accuracy of a modern global station, but the acquisition time is much lesser and density is considerably larger than a motorized global station. Thus, there is a greater productivity and facilities for the integration of high resolution scanning files in larger 3d models. Some advantages of laser scanning photogrammetry and dedicated software (Polyworks Inc) are linked to a larger density, radiometric information in original files and the friendly user interfaces for basic processing.
An important bottleneck concerns to the management of very large datasets, and the necessity of reducing information (sometimes in a dramatic way) for displaying and navigation around the object. In this work, we have developed an approach to volumetric primitives which depends strongly on the expected geometry for the visible boundary (plane, cylinder) of the object. Choice of geometric primitives imposes additional constraints, which must be avoided in the near future.
Obviously, there is a long way for pendant research still, which concerns in particular to the fusion of information arising from different sources (view- and scan-based). Some results for the fusion of information arising from different laser devices is performed thanks to the flexibility of Polyworks. A particular case of this fusion is illustrated with the following hybrid example where excavated sepulchres and chapel structures have been scanned for a multirresolution model with several resolutions and two scanners (Minolta 910 and Ilris 3D, Optech).

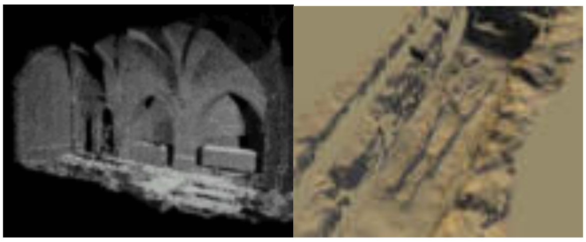

Figure 8: A partial view of the 3d model of the San Pedro Chapel in the monastery of Valbuena de Duero (Valladolid).

In this case, one can not expect simple volumetric primitives enclosing the objects. Surveying of objects require the adaptation of more flexible tools such those related to the automatic isosurface extraction [Cignoni et al, 2005]. This adaptation is a goal research, and in the near future must allow a more adaptive behaviour to the objects, independently of curved surfaces appearing in their boundaries.

6. CONCLUSIONS AND FUTURE WORK

In this work we present a range scanning approach for surveying architectural elements with archaeological vestiges. Main technical advantages of laser scan approaches are linked to the simplicity of use, the low human cost, and the global metric information of scanned sites. All these advantages allow to achieve a high productivity for generating and managing a global 3d model, supporting metric information with several levels of detail on a 3d model which can be validated for future reference or easily updated for tracking. The adopted hybrid methodology involves to a) the use of two laser scans for capturing and inserting fine information in large 3d models and b) the design of algorithms for volumetric interpretation of irregular data in terms of simplicial 3d decompositions. Next steps to be done affect to the design and efficient implementation of efficient software tools, for rendering and interactive visualization in a low-level Augmented Reality module. In this way, we hope to increase the remote accessibility to Cultural Heritage sites with archaeological and historical contents.

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