TERRESTRIAL LASER SCANNING AND LOW-COST AERIAL PHOTOGRAMMETRY IN THE ARCHAEOLOGICAL MODELING OF A JEWISH TANNERIES

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ABSTRACT:

In this paper an integrated approach for modeling complex archaeological sites is developed. Particularly, we describe a 3D modeling pipeline which integrates laser scanning and low-cost Photogrammetry over an emblematic Jewish tanneries situated in Avila (Spain). Due to its inherent complexity and the relevance of the archaeological site, Jewish tanneries constitute a perfect framework to put in practise our methodology: from the recording and reconstruction to the final interactive visualization. This multi-sensor approach would give the possibility to improve the quality of the models, without acquisition of extra laser scanner data, but using 2D images as additional source of 3D geometry based on a single image-based approach.

1. INTRODUCTION: TOWARDS THE INTEGRATION OF TECHNIQUES FOR COMPLEX SITES MODELING

Although there is no clear definition, a complex site modeling may consist of multiple structures of different types and with different levels of details and may require a multiple techniques and methods to completely modeling in 3D.

Over the past few years, a number of research teams have been addressing the use of range scans and images to develop the modeling of complex sites. Some notable projects include the Michelangelo's David project (Bernardini et al., 2002), the Great Buddha project (Ikeuchi et. al. 2003), the virtualization of a Byzantine Crypt (Beraldin et. al., 2002) and the detailed 3D representations of archaeological sites by (Ioannidis et. al, 2000). More recent approaches such as (Finat et. al. 2005) and (El-Hakim et. al., 2005) apply more sophisticated alternatives. Finat et. al. develop a flexible multi-input and multi-output approach able to support the information arising from different sensors or techniques and to provide different levels of information to users with different requirements: from users to experts. El-Hakim et. al. apply a hierarchical methodology which increases the details, accuracy and reliability as it advances from one data level to the next; i.e. they use aerial and terrestrial images for modeling the main shapes, and laser scanning for modeling fine details. Furthermore, the approach resembles the Level of Detail (LoD) concept used in visualization of complex sites.

Keep on the approach proposed by El-Hakim, *in general, most complex sites modeling specify eight requirements: high geometric accuracy, capture of all details, photorealism, high automation level, low cost, portability, application flexibility, and model size efficiency. The order importance of these requirements depends on the application's objective.*

Considering the complexity and breadth of the Jewish tanneries of Avila, a whole fulfillment of all requirements would be necessary. Nevertheless, up to know try to develop an integral system that can accomplish all demands is still unattainable, especially if a full-automated system is required. Thus, we are confronted with the need to integrate different methodologies and techniques that allow to ensure speed and accuracy of the results, while taking advance of the speed of laser scanning and the descriptive qualities of photographic images.

In this sense, our goals overlap with the work remarked of these researchers but also differ in several ways. We incorporate aerial images taken form an unmanned helium zeppelin and incorporate some algorithm related to single image-based modeling (Aguilera, 2005): i.e. camera calibration, features extraction and geometrical constraints incorporation.

Next sections aim to explore and test the possibilities open by the modeling of a Jewish tanneries through the integration of laser scanning and low-cost image-based modeling approaches. The paper presents the following structure: the first section gives an overview about related work; the second section puts across some historical aspects about the Jewish tanneries of Avila; the third section is dedicated to describe briefly the different sensors; the fourth section is devoted to the 3D modeling pipeline; finally, fifth and sixth sections shows the experimental results as well as conclusions and future perspectives respectively.

2. HISTORICAL ASPECTS ABOUT THE JEWISH TANNERIES OF AVILA

The Jewish tanneries of Avila discovered recently, constitute the most important Hispanic Jewish tanneries found in Spain up to now. In fact, these excavations show one of the most relevant and complex crafty process in Spain. Its Jewish architectonic construction belongs to medieval epoch, more precisely from century XIV, although its performance was active until century XVII, date in which an economical crisis together with the Jewish expulsion carried out its closing.

The medieval documentation about Avila surroundings revealed that in San Segundo suburbs, near Adaja River, an industrial area dedicated to skin tanner took place. This theory has sense since these types of crafty activities produce bad smell and need river proximity to pour skin rubbish.

After a preliminary phase without success, the first indications about tanneries existence start to emerge. As a result, a surface about 500m^2 was discovered. In the space opened, a set of tools such as ceramic and wood jars – more of them in a perfect state of conservation – sinks, water holes and brick canals, give an overview about the care and treatment in tanning process:

Firstly, the skins were softened and secondly the hair was removed through a water and lime solution inside the water holes. Thirdly, skins were dried and scraped in order to remove lime. Finally, the animal excrements which were used in the tanning process were introduced in special recipients to prevent the bad smell. The process end when the skins were put inside water mixed with massed barks. The whole activity was performed in a space divided in eight different halls and carried out between 9 and 15 months, while nowadays the same process takes only one week.

With relation to the future, the chemical sediments found in the archaeological site could offer more information about skin production, as well as to know if other tanneries exist in the surroundings. Due to its great conservation state, the regional institution (JCYL) aims to develop a project that allows to transform this area from a research and tourist point of view.

From a technical point of view, the Jewish tanneries of Avila present a complex and irregular topography due to the tools founded (ceramic and wood jars, sinks) and the presence of vertical walls (water holes and brick canals), thus the use of laser scanner is crucial.

3. MULTI-SENSOR DESCRIPTION

Two different types of scanners based on time of flight principle were employed in Jewish tanneries recording, with the aim of testing its performance and compare results:

- A medium-range laser scanner, Trimble GS200 (Figure 1), which incorporates a rotating head and two inner mirrors, one concave and fixed and the other planar and oscillating, allowing to acquire a scene with a large enough field of view, i.e. 360º H x 60º V, reducing the need of using lots of scan stations. Nevertheless, in order to overtake vertical range limitation, a micrometric head was adapted to laser scanner (Figure 1). The sensor accuracy is below 1.5mm at 50m of distance with a beam diameter of 3mm. Furthermore, the laser allows to acquire reflected beam intensity and RGB colours.

- A large-range laser scanner, Ilris 3D (Optech), with a spot between 5cm and 20cm and a semi-metric calibrated camera mounted on the same structure (Figure 2). Each laser scan provides at least thirty and fifty thousand points, and it is performed to have about overlapping of at least 20% between adjacent scans.

Figure 1. Trimble GS200 laser scanner (www.trimble.com) and micrometric head (red circle).

Figure 2. Ilris 3D (Optech) laser scanner (www.optech.ca) and micrometric head (red circle).

With relation to low-cost aerial images, the research group IMPAP3D has designed a low-cost system from taking aerial images (Figure 3). The system is constituted by a helium zeppelin and a digital camera fixed in a specific device equipped with servomechanisms, video and radio control which allow to obtain video signal of camera view over a monitor in real time, as well as to control the two main different rotations of the camera. These types of solutions can be used for the documentation, reconstruction and visualization of historical buildings or archaeological sites where the area of interest is small, with a difficult access and a large scale is required.

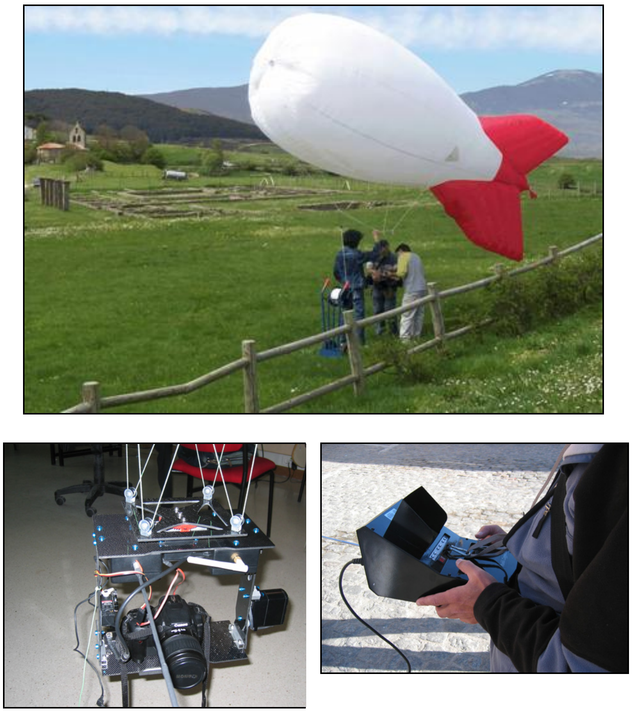

Figure 3. Aerial low-cost system

More details about this low-cost system can be found in (Gómez et. al. 2005).

Finally, in order to align under a common coordinate system both dataset, a total station, Leica TCA 2003, has been used to measure the control point's network, designed by special targets.

4. THE 3D MODELING PIPELINE

The Jewish tanneries of Avila present complex and irregular relieves due to the tools founded (ceramic and wood jars, sinks) and the presence of vertical walls (water holes and brick canals), which exhibit certain demolition state. The workspace presents a rectangular form with an approximate length of 50 meters and a width of 10 meters (Figure 4).

Figure 4. Workspace: Jewish tanneries of Avila.

The following scheme (Figure 5) illustrates the 3D modeling pipeline puts in practise over the Jewish tanneries of Avila.

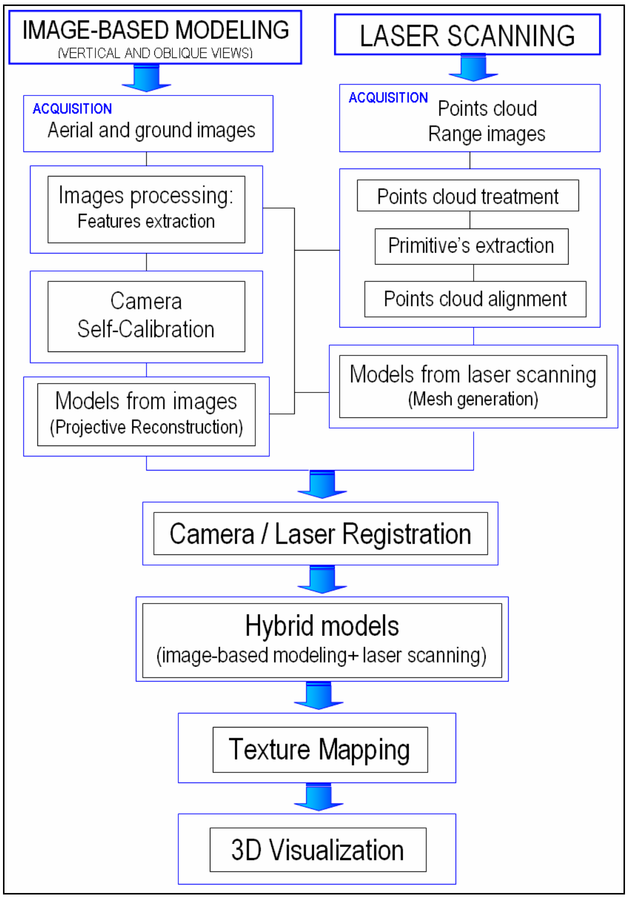

Figure 5. The 3D Modeling pipeline.

4.1 Network design

To avoid problems and register both sensors (laser and high-resolution camera) in the same coordinate system, a control points network of sixteen points was designed, which combines planar and volumetric special targets (Figure 6). These control points were surveyed accurately with a total station, Leica TCA 2003, in a global reference system

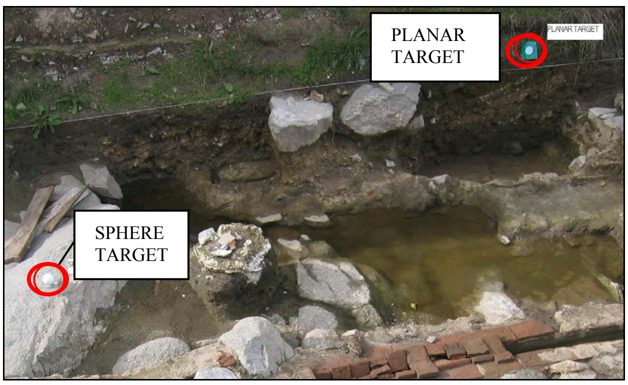

Figure 6. Special targets used in control point's network.

4.2 Images acquisition: Flight project

The flight project design consisted on one strip with five photographs. From a simple horizontal coverage point of view, one strip with five photographs would have been enough but the presence of vertical walls with the corresponding occlusions made our mind to increase photographic coverage through independent oblique image taking. Flying height was set to 40 meters which provided a ground pixel size of 0.025 m. The acquisition step ended with the taking of ground images. Several oblique images were taken from different viewpoints, in order to complement aerial images.

4.3 Scans acquisition

The use of a micrometric head (Figure 1 and 2) with both scanners reduced the number of stations considerably. Only, it was necessary five scans to obtain a full coverage of workspace. The scan resolution was setup to an average distance of 20m with a spatial grid of 20mm x 20mm. The time consumed for scan acquisition task was about six hours with one hour per station, obtaining a 5 millions cloud points.

4.4 Images processing: models from images

Camera calibration is necessary if camera settings are unknown and vary between images. But to achieve accurate camera calibration, certain geometric configurations of images are needed. From oblique images taken from the zeppelin and exploiting the geometry of structural elements and features extraction (lines and vanishing points), internal camera parameters can be estimated (Aguilera, 2005). Furthermore, if priori information about the object supported by geometrical constraints is known, external camera parameters could be determined as well. The own properties of vanishing points and their correspondence with the three main directions of the object establish directly the orientation of the reference system, while the view point provides origin and scale to the reference system.

Once aerial and terrestrial images have been calibrated, there are a wide selection of alternatives to obtain model from images: from the classical restitution through stereo images using aero-triangulation methods (Kraus, 1993) or even anaglyphs techniques, to image-based methods supported by exploiting multiples views and projective geometry (Hartley and Zisserman, 2000) or single views and geometrical constraints (Aguilera, 2005).

In our case, some relevant elements such as vertical walls were extracted through classical restitution using the aero-triangulation method and stereo images. These elements performed as geometrical constraints in mesh generation from laser points cloud. Furthermore, some topological criterions together with geometrical constraints were added exploiting image-based modeling and projective geometry.

4.5 Scans processing: models from laser scanning

The acquired laser data are often characterized by the presence of elevated noise which must be removed with specific filters (preliminary treatment) before starting with the manipulation of the data.

Outliers due to partial reflection of the laser spot at edges, multiple reflections of the beam, range differences originating from systematic range errors caused by different reflectivity of surface elements, erroneous points caused by very bright objects (lights).

Redundant data, due to high point density in overlapping scans areas or short object distances from the scanner.

Next, each scan must be registered in the same coordinate system. This alignment procedure is performed through the Iterative Closest Point (ICP) algorithm (Besl&McKay, 1992). Pairs of candidate corresponding points are identified in the area of overlap of two range scans. Subsequently, an optimization procedure computes a rigid transformation that reduces the distance (in the least-square sense) between the two sets of points. The process is iterated until some convergence criterion is satisfied. The general idea is that at each iteration the distance between the two scans is reduced, allowing for a better identification of true matching pairs, and therefore an increased chance of a better alignment at the next iteration.

Finally, once the different scans have been filtered and registered in a common coordinate system, a model can be obtained from the full-resolution scan, incorporating the geometrical constraints and topological information extracted from image-based modeling. A constrained triangular mesh generation based on Delaunay algorithm was applied over the points cloud.

4.6 Multi-sensor processing: hybrid models

The idea developed in this stage, is based on the use of calibrated high-resolution images taken from air and ground not only to map textures but also to improve 3D laser segmentation and complete scans with additional geometry. This would give the possibility to improve the quality of the models, without acquisition of extra laser scanner data, but using the already available 2D images as additional source of 3D geometry.

In this sense, the single image-based approach developed allows to complement the 3D laser scan model in three different ways:

- Improving the 3D laser scan model. Through the extraction of features (lines and points) over the high-resolution images and knowing the camera calibration, several geometrical constraints can be automatically incorporated into the 3D laser scan model. On one hand, 2D edges can be used to guide the correction of 3D edges over triangular mesh generated from laser scanner, event pretty common with the presence of breaklines, joints, etc., and on the other hand, extracting 3D edges automatically from isolated buffer areas in the cloud points.

- Incorporating additional information from images in such areas where no laser scan data is available due to shadows, occlusions, etc. or to increase the density of points in areas of high interest and 3D content. Again, through the extraction of 2D features and the knowing of camera calibration, additional geometric information can be incorporated into the 3D model supported by constraints.

- Adding contextual information, based on integrating cylindrical or spherical panoramas with the 3D model generated. Aerial images taken from zeppelin allow to represent the remainder of the landscapes and far objects. This shows the structures in their natural setting and increases the level of realism. We have used a few joint 3D points between the panorama and the generated 3D model to register both datasets together.

5. EXPERIMENTAL RESULTS

This paragraph shows the results of testing our 3D modeling pipeline over the emblematic Jewish tanneries of Avila (Spain).

Following the multi-sensor approach for the 3D modeling of Jewish tanneries the next results were obtained:

A cloud point treatment was carried out using spatial and topographic filters to reduce information and to eliminate noisy and unnecessary data (Figure 7). Manual segmentations were also applied to eliminate those features that were not eliminated by filters. This task consumed 2 hours.

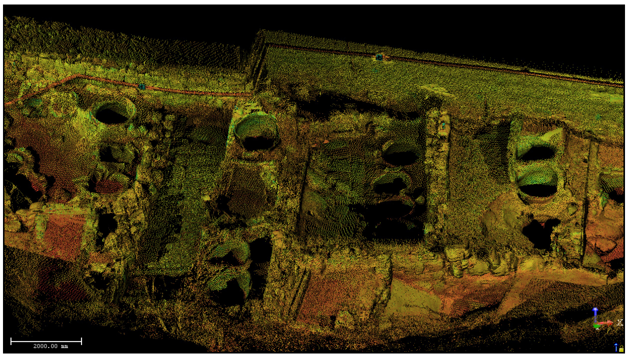

Figure 7. 3D model obtained from laser scanner.

A solid model (Figure 8) was conformed following a hybrid strategy: on one hand triangulating points cloud from laser scanner and on the other hand adding geometrical constraints and topology from image-based modeling approach. This semi-automatic task consumed 4 hours.

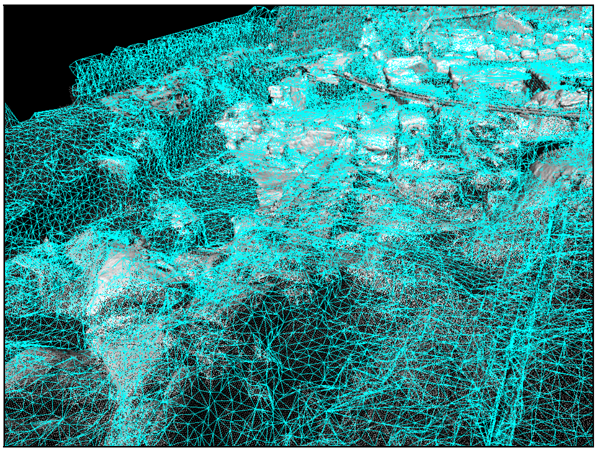

Figure 8. Constrained triangular mesh obtained from laser points cloud and image-based modeling.

After model triangulation a cross-map with an equidistance of 10 cm (Figure 9) was generated automatically with the aim of providing an altimetric framework.

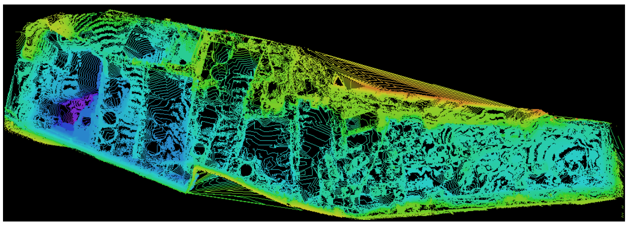

Figure 9. Cross-map with an equidistance of 10cm.

As another hybrid product, a 360-degree panorama surrounding the archaeological site is integrated to provide an additional complement to model the scene (Figure 11). Oblique aerial images acquired from zeppelin were used to generate a panorama georeferenced to the scene.

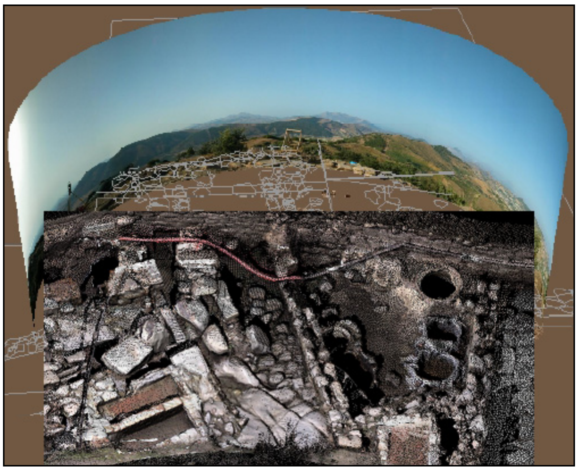

Figure 11. 3D final textured model integrating a panoramic image as background.

Finally, a manual procedure based on mapping high resolution textures was performed. An external digital camera was registered to laser model identifying correspondences between 3D points cloud and 2D image points. As a result, a final laser model with high resolution RGB values projected onto the points cloud was obtained (Figure 12). This task was especially delicate due to the different illumination conditions present in digital images. A total of 8 hours were required to map high-resolution textures properly.

Figure 12. 3D final textured model integrating high-resolution images from an external camera.

6. CONCLUSIONS AND FUTURE PERSPECTIVES

We have reached clear conclusions about the effectiveness of combined techniques for complex sites modeling. Through the use of laser scanner and low-cost aerial Photogrammetry, we can completely model a complex site with realistic details, especially archaeological sites where the prevalence of an elevated viewpoint is crucial. The results were highly accurate, fully detailed, and photo-realistic. The cost and time required was much less than if we had performed a similar work with traditional techniques. Nevertheless, put in common two different sensors such as camera and laser is not an easy and straight path; several problems related with their own dataset features i.e. resolution or field of view arise, making more difficult the multi-sensor processing.

In this sense with relation to future perspectives, the presence of shadows and holes is a problem not completely solved in this case. A texture mapping can pose difficult problems in providing complete and accurate coverage of a complicated model. Therefore, develop algorithms that allow to handle the resulting problem of occlusions, illumination properties and transition between junctions, would let to achieve a realistic and integral representation of the object.

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