RECORDING AND VIRTUAL MODELING OF A ROMAN VILLA THROUGH LASERSCANNING

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ABSTRACT:

The recording and 3D virtual modeling of large and complex cultural heritage sites is currently receiving much attention due to the emergence of a wide array of new technologies which greatly support the efficient generation, administration and analysis of such models. Nevertheless, the problem remains the huge effort and costs that has to be invested to obtain realistic models. Besides on-site measurements, much time is often spent in manually rebuilding the whole site with a CAD package or a 3D-modelling tool.
This paper tries to progress in this direction providing a flexible workflow to archaeological sites modeling, starting from the acquisition system and ending with the generation of a virtual model in three dimensions. The general objective of this paper is to contribute to the standardization of archaeological digital recording. Particularly, this paper outlines the methodology for recording and virtual modeling of a roman villa through laserscanning. Also, the capabilities and limitations of this technology compared with low-cost photogrammetry are put across.

1. INTRODUCTION

Much has been written during years about the methodological background of excavating, but only a small amount of publications can be found dedicated to describe a flexible and accurate methodology for the archaeological recording and modeling.

For a long time in its history, archaeology was considered a science dominated by pragmatism and adapted its methods or techniques from other disciplines, mainly natural sciences. One of the most important realizations of the last centuries, that changed archaeological research, was the fact that any archaeological site is stratified and any archaeological stratification is unique (Harris, 1989). Stratigraphy, the description and interpretation of stratification is the main key for any further analysis of any archeological finds. Nevertheless, it has been the recent emerging and availability of new digital techniques and technologies offered by Geomatics what has caused a revolution in the archaeological research. Particularly, laserscanning implies the possibility of obtaining new products not only from the surveying phase but also in the representation and visualization phases, with the aim of having a rigorous and digital description of objects, structures and sites, but also to provide powerful instruments for data analysis and exploration in view of a successive reconstruction and restoration. Furthermore, laserscanning technology provides the ability to acquire, visualize and analyze graphical information in combination with other types of datasets with the passage of time.

With laserscanning, archaeologists are able to recording the topographical development of sites in an efficient manner that was almost impossible to carry out through classical surveying techniques. However, selecting the most appropriate 3D modeling approach to satisfy all requirements for a given application is not always an easy task, in particular in archaeological sites.

The general objective of this paper is to contribute to the standardization of archaeological digital recording. Particularly, this paper outlines the methodology for recording and virtual modeling of a roman villa through laserscanning. The paper presents the following structure. After this introduction, Section 2 describes briefly some historic aspects about the roman city discovered recently. Section 3 explains in detail the recording and virtual modeling approach. Section 4 establishes a comparison between this laserscanning technology and low-cost photogrammetry. A final section is devoted to discussion.

2. THE ROMAN VILLA OF SAN PEDRO DEL ARROYO

The roman villa of San Pedro del Arroyo (Avila, Spain) was discovered by chance one year ago due to some works for enlarging the cemetery. It is supposed that this villa belongs to the IV century. Several tessellated pavements and vertical walls have been emerged in a very well state of conservation. After the official find, the works were interrupted and several archaeological prospections were performed in order to confirm the main limits of the archaeological site.

Afterwards, an archaeological excavation campaign was performed by an archaeology company, Foramem S.L, and required three months. Several main rooms were discovered as well as a big mosaic which contains a mythological hunter scene (Figure 1).

Figure 1. A partial view of the roman city and the big mosaic discovered.

The need for 3D modeling was demanded by archaeologist with the aim of obtaining whatever metric measurement, not only about the surface or volume of the excavation, but also about the artefacts prospected as well as its alignment. This last aspect would allow archaeologist to plan more excavations campaigns and perform scientific research about the roman villa.

3. FULL LASERSCANNING PIPELINE

The purpose of using laserscanning technology for the recording of the roman city was twofold. On one hand, we want to put in practise this technology in an archaeological background, and on the other hand and considering our previous experience in others archaeological sites (Gómez Lahoz et. al, 2005), we want to know the capabilities and limitations of this technology compared with low-cost photogrammetry.

Laser scanning technology with its automated data capture capabilities is bringing new perspectives and can satisfy most requirements of this type of applications. Laser scanning represents today the most advanced technology available for measuring and documenting complex objects. Terrestrial laser scanning technology is based on active range sensors measuring directly the distance between the sensor and points over the surveyed object. Objects that can be documented by 3D scanning, range from the sizes of small artefacts or pieces to whole archaeological sites. Lasers scanners directly produce a huge number of 3D points. The resulting point cloud can be used to extract CAD elements or - by using point triangulation - to create a 3D surface model. Additionally, images can be mapped onto the model to get a virtual copy of the real object.

In our case, we established four stages to get a complete modeling of an archaeological site: data acquisition, data processing, data modeling and data visualization.

3.1 Data acquisition

The data acquisition phase was performed through two different campaigns which overlap with the archaeological prospections. In the first one, the scanning phase was focused on the main room and vertical walls, while in the second one, the scanning phase was focused on the big mosaic and the tessellated pavement.

Three different kinds of dataset were acquired with two different sensors: a time of flight laser scanner, Trimble GX200

(URL1), and a high-resolution digital camera, Nikon D70 (URL2).

At first, several control points defined by the archaeologist are surveyed with the laser scanner, with the aim of establishing a local coordinate system and the vertical direction. Also, these control points are used to align the single scans from several scanner positions into one archaeological coordinate system.

Secondly, the archaeological site and some relevant elements were scanned using different resolutions. An average spatial resolution of 2 cm was used for recording the complete archaeological site, while 5 mm was setup to acquire special details such as the big mosaic and some relevant vertical walls (Figure 2). A total of eight stations were needed to record the whole site.
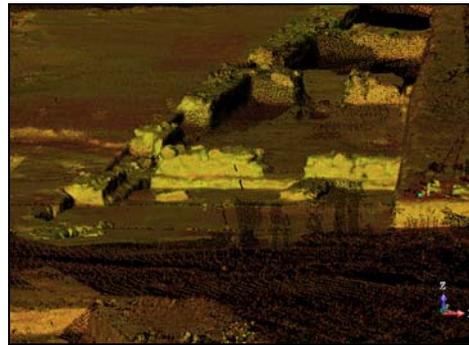

Figure 2. Detailed scanning of vertical walls.

At last, during the scanning process, panoramic and high-resolution images were taken with a digital camera from a position near to laser scanner. These images try to complement the poor radiometric information provided by laser scanner.

3.2 Data processing

In the process of processing an archaeological site from unorganized point clouds, a number of steps are involved. One of the critical steps is segmentation, which contributes to reduce irrelevant information, reject noise, as well as segment the structures from the background of the original laserscanning point cloud. Particularly, manual segmentations were applied in the point cloud with the aim of reducing unnecessary laser dataset. Also, automatic segmentations based on orthogonal sections were applied in order to extract profiles and height-maps (Figure 3).
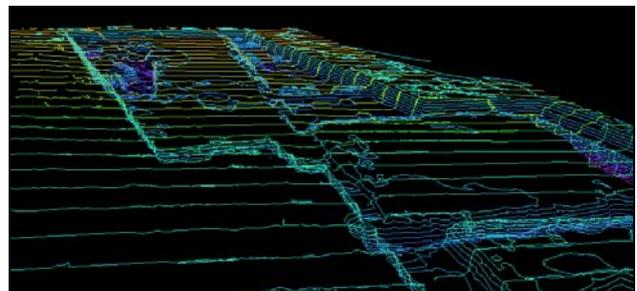

Figure 3. Profiles and height-maps.

On the other hand, an alignment of scans was applied in through a double process. Firstly, registering each scan belonging to a specific campaign and secondly registering both campaigns in the local archaeological reference system. Natural details and the surveyed control points were used to perform the alignment. An overlap about 25% was maintained to guarantee good quality in the iterative registration process based on the ICP (Iterative Closest Point) algorithm (Besh and Makey, 1992).

The reliability and accuracy of the alignment method affect the result of the final structures extraction to a large extent.

Finally, a local reference system inherited from the archaeological dataset was applied to the laser model, in order to put in the same framework the measurements and drawings provided by the archaeologist together with the 3D model.

3.3 Data modeling

For some modeling applications, like archaeological sites, where the object is mainly described with straight lines, laser scanner technology does not provide a final solution. Therefore, a modeling strategy is required in order to pass from point cloud to surface and consequently to CAD or even to orthophotomap products.

Regarding geometry, a double strategy was developed:

- Complex geometries with irregular forms were modelled based on triangular meshes. Particularly, Delaunay triangulation (Delaunay, 1934).

- Basic geometries such as vertical walls or the own floor have been modelled based on basic primitives. Particularly, 3D planes are extracted by an automatic fitting of planar primitives with points of the object, while 3D lines are extracted as a result of planar surface intersections.

On the other hand, regarding radiometry and hybrid strategy based on the co-registration of sensors (camera and laser) was performed. In this way, through a texture mapping technique, the high-resolution images acquired with the digital camera were mapped onto the 3D laser model, achieving photo-realistic 3D models. A manual identification of homologous points between laser scanner point cloud and high resolution images assisted by the user, allowed us to compute the camera model and thus to know internal and external camera parameters. As result, for each triangular face of the 3D laser model the corresponding image coordinates were calculated. This approach is performed automatically based on the Anchor Points method developed by (Krauss, 1993). This method has three main steps:

(i) Firstly, laser model image-coordinates are computed through camera model and collinearity condition.

(ii) Next, a correspondence between each face of the laser model with each face of the high-resolution image is established.

(iii) Finally, a projection of the photographic texture between the face of the high-resolution image and its homologous in laser model is performed. In this sense, each triangular face

receives a specific transformation model well known as affine transformation.

As a result of this process the following figure (Figure 4) illustrates the process applied over the big mosaic.

Figure 4. Texture mapping over the big mosaic.

Finally, due to its metric and texture properties, a true orthophotomap was developed based on the surface model from scanning and the registered high-resolution images (Figure 5). Cartographic data such as heights and some relevant lines were incorporated manually to the true orthophoto.
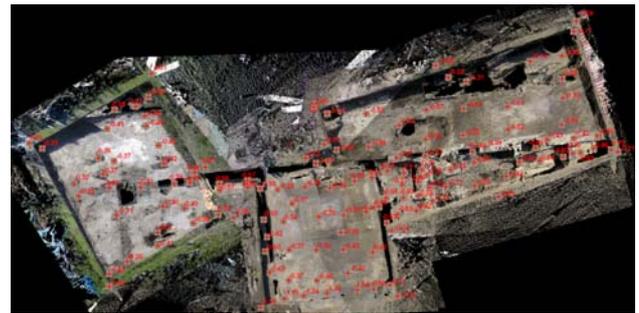

Figure 5. Orthophotomap of the roman villa in San Pedro del Arroyo. Pixel size 30mm.

3.4 Data visualization

Finally, the visualization of a 3D model is often the only product of interest for the external world and remains the only possible contact with the model. Moreover, an interactive visualization of the object enables us to obtain impossible views and perspectives to support further analysis tasks. Therefore, a realistic and accurate visualization is often required. However, working with laser scanner dataset complexity increases considerably, especially if we consider the volume of information, so the modeling pipeline described before remains crucial to transform our laser polygonal models to VRML automatically.

The VRML (Virtual Reality Modeling Language) format was the standard chosen to provide an interactive visualization of the results guaranteeing flexibility and scalability in the visualization at the same time, so different 3D models can be incorporated and managed easily. In this way, an automatic transformation of the reconstructed 3D model into a topological structure (points, lines and surfaces) sorted hierarchically in a

nodes network was performed, allowing three different levels of visualization: wireframe, shaded and textured.

On the other hand, taking the true orthophoto generated as basic support together with some elevation measurements corresponding to vertical walls, a simplified representation in 3D was generated using the popular tool SketchUp (URL3) (Figure 6). These representations complement the metric documentation and contribute to improve the interpretation of the archaeological site for a non expert public. Another relevant advantage about these graphic products is their easy incorporation to Google Earth platform. Therefore, a global dissemination and advertising campaign about the archaeological cultural heritage could be a reality. Moreover, through this approach some important barriers could be broken such as the time limitations in some archaeological prospections or the accessibility problems to some excavations for people with physical disabilities.
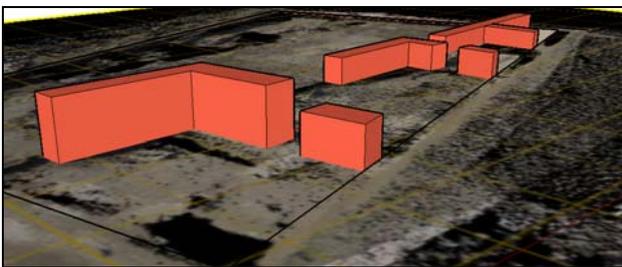

Figure 6. Archaeological site modeling through basic primitives.

4. A COMPARISON WHIT LOW-COST PHOTOGRAMMETRY

Sometimes, low-cost photogrammetric systems composed by hardware and free software devices are the key to success to offer archaeologists all the powerful tools for fast and accurate recording and mapping of archaeological sites. Use of low-cost platforms for photography has been reported in many cases (Miyatsuka, 1996.), (Theodoridou, et. al., 2000), (Karras et. al., 1999) and (Zischinsky et. al., 2000). Kites, balloons, radio controlled model helicopters, rope-way, fish rods and well buckets are only some of the ingenious methods photogrammetrists are using for low altitude photography. In most of these cases, the ideal layout of the photographs is not fulfilled. This is reported in the case of the radio controlled model helicopter (Tokmakidis and Skarlatos, 2002) and in the case of the balloon (Karras et. al., 1999), and generally in any case where the photographer cannot fully control the position (kites, balloons) or he is not physically behind the camera (rope way, fish rods, well buckets). Although the radio-controlled helicopter with a radio link for transmission of the imaged object on the ground does not seem to suffer from the aforementioned problems, this is not the case. Therefore the scale is not equal between photographs and overlaps are far from the ideal. Some of these problems have been improved recently; (Skarlatos et. al., 2004) report several good results obtained in archaeological sites using a radio controlled model helicopter, as a semi-metric camera platform; (Eisenbeiss, 2005) presents an autonomous helicopter system that adds a GPS/INS system providing good results. However, both approaches continue to require highly skilled operators to control the helicopter; more recently, (Aguilera et. al., 2006)

propose an approach which overlaps with the work done by these researchers but also differs in several ways. Firstly, in relation to hardware or low-cost acquisition system, an original and robust camera platform that guarantees stability and quality in the photographic taking is designed allowing the user to acquire rigorous vertical (stereoscopic) and oblique images easily. Secondly, free software and tools are developed to provide virtual archaeological sites modeling.

However, the low-cost approaches remarked upon above are not suitable for all kinds of objects. Particularly, when the objects have very irregular surfaces and not a clearly defined structure, laserscanning will probably yield better results than photogrammetry. In this sense, through laser scanner we have the availability of real time 3D coordinates for irregular surfaces. The striking capability of collecting hundreds or even thousands of points per second is praised by producers and operators.

The main difference between scanning and low-cost photogrammetry is obvious: while photogrammetric surveying is an indirect data acquisition method (images are needed before measurements can be executed), scanning produces 3D points directly. As geodetic surveying instruments, scanners cannot be used when the object or the observation platform is moving. In these cases, photogrammetric images, which can be acquired with very short exposure times, are the only means of metric documentation.

In the contrary, laser scanner technology continues relying on a strong hardware and software dependence. In fact, some companies have invested heavily on digital implementations of laserscanning principles, and lead the market in order to obtain massive range data production. Consequently, prices remain high and the access to laser scanner equipment continues being limited only to those who can afford it.

5. DISCUSSION

The presented paper has investigated and developed a laserscanning methodology for archaeological sites modeling. We proved the applicability of this approach in the roman city of 'San Pedro del Arroyo'. Also, a comparison with low-cost photogrammetry has been outlined.

As a result, the use of laserscanning in archaeology is becoming quite common due to its quality and potency, but until now end users are discouraged by cost, time needed to processing data and the fact that the final result is unmanageable. In this way, a combination of image and range-based methods, as no method by itself can generally satisfy all the recording requirements at the same time. The requirements specified for many applications, including digital archiving or mapping, involve high geometric accuracy, photo-realism of the results and the modeling of the complete details, as well as some automation, low cost, portability and flexibility of the technique.

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