IMAP3D: LOW-COST PHOTOGRAMMETRY FOR CULTURAL HERITAGE

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KEY WORDS: Cultural Heritage, Archaeology, Low-cost technique, Helium-Zeppelin, Software development.

ABSTRACT

In the new Digital Era the rapid development of digital technology allows us to obtain easily the high resolution images through Digital Photogrammetry or the detailed 3D data of the object by the technique of laser scanner. Nevertheless, both techniques present several drawbacks: in the case of aerial photogrammetric applications, image acquisition is one of the most expensive steps. Especially if aerial images must be taken, the expenses are always high because of the high-cost of aircraft flight. In the case of laser scanner, the own cost of the material is one of the main problems. Furthermore, to obtain a final product is yet something difficult to overcome and a time-consuming activity.

The research group IMAP3D has developed a low-cost methodology based on shutting photographs from an unmanned aerial platform completed by terrestrial exposures. 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. This methodology is complemented with the development of different tools that enable us to process the input data captured by the zeppelin: from the camera self-calibration and 3D reconstruction of the model to the automatic generation and visualization of Digital Elevation Models (DEM) and ortophoto in GeoVRML. Particularly, the methodology developed has been tested over the emblematic archaeological settlement of Clvnia situated in Castile (Spain).

1. INTRODUCTION

Restoration, recording, reconstruction or even study of an archeological site requires accurate plots. Traditional methods of string grids do not provide accuracy standards and simple survey of the site can only provide a layout with a few accurate points connected with vectors, without any further information. Furthermore, both methods have the disadvantage of extra people working within the archeological site for a prolonged period of time, which increases the economical cost, as well as the possibility of accidental destruction of important findings (Ioannidis, 2000).

In this way, the use of Photogrammetry in Archaeology is becoming quite common due to its property of combining metrical characteristics together with a high level of radiometric detail, but until now end users were discouraged by cost, time needed to take photographs from air and the fact that the final result was still a vector plot. Evolution of computers and the passage from analytical stereo plotters to digital ones, re-established photogrammetric procedures and applications improving its capabilities and final products. Nevertheless, photographic taking continued being a ‘bottleneck’ that required of expensive photogrammetric flights or complex portable structures.

In this sense, the use of unmanned low-cost aerial platforms as balloons, blimps, paragliding or even kites allow a new and economical way of doing Photogrammetry, mainly when large-scale is required and other surveying techniques do not fulfil the expected requirements.

This paper deals with the experience carried out by the research group IMAP3D in the documentation, reconstruction and visualization of the archeological settlement of Clvnia, especially with the House I. The paper presents the following structure: the second section explains some historical aspects about Clvnia, as well as a brief description of the House I and its excavation strategy. The third section puts several ideas across about photogrammetric technology and its divergent evolution in the last years. The fourth section gives an overview of the aerial platform designed. Next, fifth section is devoted to the description of low-cost methodology for the documentation, reconstruction and visualization of Cultural Heritage. A final section is devoted to sketch some future activities and conclusions.

2. HISTORICAL ASPECTS AND EXCAVATION STRATEGY

Clvnia has a celtiberian origin, but it was refunded by romans in Julia-Claudia time, with a foundation attributed to one of the first roman emperors (August or perhaps Tiberio). It was under the administrative reform of Claudius I (41-54 a.c.) when Clvnia acquired its maximum splendor being the capital of one of the seven roman ‘convents’, and becoming the juridical and religious centre of Iberia. Around the second half of the first century and the second century, Clvnia occupied about a hundred of hectares with a large diversity of civil buildings (imperial hot baths, forum, theatre) and a population about a hundred thousand people. Its condition as representative centre of the roman power gave an exceptional quality to the whole archaeological site till its abandon between the fourth and seventh centuries of our era.

Nowadays, the roman city of Clvnia Sulpicia situated in the province of Burgos (Spain) constitutes one of the most important archaeological sites in Spain. Particularly, the House I which was excavated by Taracena and later by Palol in the thirties presents its limits to the east and north almost unknown, being impossible to interpret them correctly. The strong transformations hold along more than three centuries and the intense devastation and pillage along medieval and modern ages has originated a large dispersion at religious and civil buildings which makes difficult an understanding of vestiges. Nevertheless, excavations in last years in different places of the archaeological site have provided a very large number of roman vestiges in a limited stratigraphy for major arts (sculpture, entablatures, etc), but very rich in ceramics, industrial objects

and some fragments of ornamental sculpture with military motives frequent in commemorative buildings. Last archaeological excavations are focused towards the recovery of architectural elements in monumental zones on one side, and the recovery of ceramic vestiges and reliques in houses.
The recent incorporation of new technologies as laser scanner and aerial high resolution images provide data for achieving a better understanding of the current state of houses and public spaces, and the different phases of the excavation with a special attention to estratigraphical issues. All this information will be incorporated to a global model of the archaeological site in the next future.

3. TECHNOLOGIC EVOLUTION: TOWARDS A DIVERGENT DYNAMIC

It was in 1858 when Nadar (Gaspard Felix Tournachon) used a balloon to obtain the first aerial photograph while Aimé Laussedat developed the basic methodology to survey the earth surface by means of aerial - also terrestrial - photographs.
From this moment and for the next 100 years Aerial Photogrammetry grew to become the most confident way to obtain extensive cartography. This evolution was characterized by a 'convergent' trend. Technology developers generated more and more efficient and sophisticated devices (cameras, lenses, shutters, films, plotters, airplanes) and methods (according to Bonneval, the 'Méthode Générale de la Photogrammétrie') which lead to a highly specialized discipline by the mid-sixties.
Nevertheless, since the beginnings of the analog-digital transformation, this profile is being inverted. Softcopies and software have pushed physical based devices and methods to the borders of extinction. Photogrammetric specific hardware has almost disappeared and a new, wide and breadth, community of users and developers is taking advantage of an open - and somewhat uncertain - field. Nowadays the situation may be portrayed by the following issues:

- New sensors and, above all, fusion of new sensors: Global Positioning System, Inertial Sensors, Large Format Digital Compound Cameras, Pushbroom Scanners, Laser, Lidar, ...
- New means of delivering and exchanging cartographic information.
- New algorithms which not only render geometry and radiometry, but also provide quality figures.
- New technological neighbors and new relations among these: Photogrammetry, Image Processing, Remote Sensing, Computer Graphics, Robot Vision, ...
- Even though the raising paradigm covered by the 'full automatization' target (well described by the motto coined by Ackerman 'Redundancy vs. Intelligence' or the one proposed by Schenk 'Quantity vs. Quality') there is a spreading field in which architects, archaeologists, risk preventers, land managers, ...and many others non-skilled geomatic professionals may participate in a passive (users) or even active (designers, developers) fashion .

From the archaeological documentation point of view, we may consider two extreme objects which lead to different approaches or to merge ones as long as the target object may lie in the middle of the continuous space between these extremes:

1) A relative well preserved building with well defined features and structured by vertical planes or analytical surfaces, accessible from an earth point of view.
2) An eroded (and even buried) site with irregular geometry and with a mainly level disposition. In this case, very powerful sensors, such as laser scanner are insufficient while belonging to the same mean plane the object does. It becomes necessary to achieve a 'bird' point of view. In the case of Photogrammetry, we must use stereoscopic identification / exploration to render the irregular site surface and so, a close control of the twelve degrees of freedom of the images is essential.

4. SYSTEM DESCRIPTION

Use of low-cost aerial platforms for photography has been reported in many cases (Miyatsuka 1996, Theodoridou et. al. 2000, Zischinsky et. al. 2000, Karras et. al. 1999, Ioannidis et. al. 2000). Nevertheless, in the most of cases remarked above the ideal layout of the photograph is very difficult to achieve. Problems regarding to scale variations, overlaps and rotations are very common. In this sense, the research group IMPAP3D has designed a robust system that guarantees stability and quality in the photographic taking. The system developed contains two main units:

- Flight Unit
- Ground Control Unit

4.1 Flight Unit

In the flight unit, there are four main parts (Figure 1, 2). These are:

- Helium Zeppelin: with a capacity of 11 m that provides a lifting force of more than more than 5 kg.
- Picavet: this is a device, implemented in 1912 by Pierre L. Picavet, which consists of a rigid frame suspended, by means of a continuous string and pulleys, from another string attached to the blimp body. The result is a relative stable self-levelling platform despite the wind.
- Camera Platform: to support the camera while providing motion with two degrees of freedom: one rotation upon a vertical axis and another rotation upon a horizontal one. Both axes are endowed with gyroscopic devices to increase stability. .
- Camera: A Nikon D70 with a resolution of 3000 x 2000 pixels.

Figure 1. Zeppelin and Picavet system.

Figure 2. Camera Platform

4.2 Ground Control Unit

Ground control unit is constituted by three parts (Figure 3). These are:

- Monitor, to obtain a field of view pre-visualization in real time.
- Remote controllers for controlling the acimuth ant tilt of the camera frame and for shutting the camera.
- Control ropes to provide a control over the planimetric and altimetric position of the blimp.

Figure 3. Monitor and remote controller

5. LOW-COST METHODOLOGY

Next, the steps of low-cost methodology for recording and managing the Cultural Heritage are explained.

5.1 Design: sensor and network geometry

The House I presents an irregular object structured on a horizontal frame exhibiting certain demolition state. The object interpretation demands a datum definition in which the main plane is the horizontal one. It also needs to consider the existence of high relieves.
The project design consisted on three strips with three photographs each. From a simple horizontal coverage point of view, one strip with three photographs would have been enough but the presence of vertical walls with the corresponding occlusions made our mind to increase photographic coverage. Both, base line and lateral overlaps were established to 0.7. Flying height was set to 80 m. which provided a ground pixel size of 0.05 m. To avoid problems we designed a twelve control points network with an average of eight control points per photograph.

5.2 Measurements

The field campaign was relative successful as the wind did not surpass 10 km/h until ten o'clock in the morning. By this hour, enough photographs in a stereo arrangement (Figure 4) had been shut and we could continue with obliques (Figure 5) -much less restricted by the wind-. The day was rather cloudy and images are relatively free from cast shadows.
A four person team dealt with the campaign: two persons (this was recommendable as the terrain presented some obstacles) to drive the blimp, one more to manage the camera attitude and shutting controls and one more to document the activities and acquire surveying measurements through RTK GPS technique.

Figure 4. Vertical image over the House I

Figure 5. Oblique image over the House I

5.3 Photogrammetric data processing

The different types of images captured from air and land allow us a wide selection of alternatives to process the photogrammetric data: 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).
On the other hand, the own 'low-cost' philosophy inhered motivates to develop tools (Aguilera, 2005) supported by open source code that provide us autonomy in 3D reconstruction and visualization of Cultural Heritage.
Next sections briefly describe the photogrammetric data processing, consisting of camera self-calibration, DEM

extraction, ortophoto generation and visualization of the results.

Camera self-calibration

From oblique images taken from the zeppelin and exploiting the geometry of structural elements (vanishing lines and points), internal camera parameters, principal point and focal length, can be estimated (Aguilera, 2005). Furthermore, if priori information about the object supported by geometrical constraints is known, external camera parameters, rotations and pose camera, can be determined. 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 (Figure 6).

Figure 6. Camera self-calibration supported by oblique image geometry: extraction of vanishing lines and points

DEM extraction

A Delaunay triangulation converts the cloud of points extracted by photogrammetric procedures into a consistent polygonal model or mesh (Figure 7). Delaunay triangulation algorithm is based on *Incremental Method or Supertriangle Method* (ASPRS, 2004). In this way, we start with a huge artificial triangle which round the cloud of points. Next, we triangulate the cloud of points from the first one to the last one, taking the artificial triangle as part of the triangulation. Once the triangulation has been done, we only have to reject those segments whose extremes belong to the initial triangle. Delaunay criterion ensures that no vertex lies within the interior of any of the circumcircles of the triangles in the mesh.

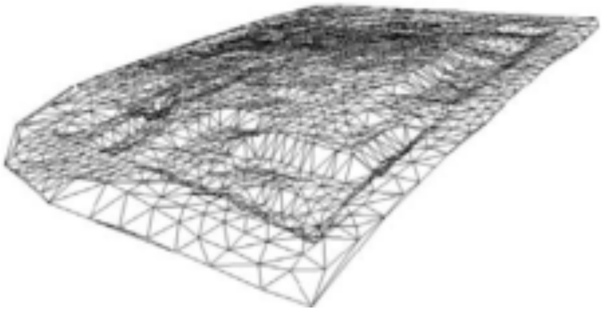

Figure 7. Clvnia's DEM extraction

Ortophoto generation

The basic photogrammetric deliverable in heritage conservation is ortophotography. Ortophotos provide a combination of geometric accuracy with textured representation for the documentation of Cultural Heritage.

In this way, once DEM has been extracted and camera has been calibrated, an ortophoto (Figure 8) is generated geo-referencing a photographic texture over the DEM through 'Anchor Points Method' (Kraus, 1993). This method has three main steps:

1º Step – Firstly, DEM photo-coordinates are computed through camera parameters and collinearity condition.

2º Step – Next, a correspondence between each face of the DEM with each face of the image is established.

3º Step – Finally, a projection of the photographic texture between the face of the image and its homologous in DEM is performed. In this sense, each triangular face receives a specific transformation model well known as affine transformation.

Figure 8. Clvnia's ortophoto generation

5.4 Visualization of the results

Regarding to visualization step, an automatic transformation of 3D photogrammetric data into a topological structure (points, lines and surfaces) sorted hierarchically in a nodes network is performed. In this sense, GeoVRML as a modeling language, can be applied to many areas such as cartography, architecture, archaeology, civil engineering, medicine, and last but not least, tourism; providing the necessary characteristics in order to establish an efficient and quality communication between cartographical information and 3D visualization on Internet (González, 2005).

Topological structure

Geometrical nodes contain information about the 3D model structure and camera.

Appearance nodes contain information about the materials and photographic textures, as well as the transformation parameters that allow to relation the geometry of the object with the texture.

Metadata nodes contain specific information about the node: format and size of the image, number of faces, number of lines, surface, length, accuracy, etc.

Hierarchical structure Finally, nodes corresponding to 3D model are sorted by a hierarchical level inside the scene.

1º hierarchical level [H1]. It is constituted by system coordinate node, *Datum Node*, and *Camera Node*.

2º hierarchical level [H2]. It is constituted by the structural lines and faces of the model, *Line Node* and, *Face Node*.

3º hierarchical level [H3]. It is constituted by the own properties of the object, *Metadata Node*.

6. FUTURE ACTIVITIES AND CONCLUSIONS

Currently, we are trying to test our methodology over complex sites mainly where other surveying techniques don't allow an efficient documentation: monuments with a difficult access in urban areas, roman aqueducts, etc.

A mid-term challenge is the adaptation of helium zeppelin to remote sensing applications in order to obtain multispectral images for classification tasks, incorporating ultraviolet, infrared and visible filters to the camera.

Finally, regarding to the conclusions we can affirm that the low-cost methodology developed has lived up to expectations, achieving good results even with the presence of wind. Precisions around 0.05 meters and 0.03 meters have been obtained in planimetry and altimetry respectively. Regarding to rotations and compared with conventional aerial photogrammetric cases, discrepancies lower than 5 degrees have been obtained.

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