Rapid Mapping methods for archaeological sites

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Abstract **– The paper focuses the feasibility of rapid mapping methods in archaeological site, enlightening the flexibility in different kind of ancient buildings and sites surveying with the aim to 3D document and to model objects of interest with rich geometric and radiometric contents and high accuracies.**

After discussing constraints to be considered for the correct use of rapid mapping methods, a case study will be described in which an UAV photogrammetry survey, integrated with a terrestrial survey using a mobile laser scanner based on SLAM technology (Simultaneous Localization and Mapping) was performed. A Lidar (terrestrial laser scanner - TLS) survey as ground truth, that accompanies the use of ground control points for the evaluation of the metric results, completed the application. The case study is a great importance area in the ancient city of Hierapolis (TK), the Ploutonion, in which excavations were recently completed and the public exhibition was inaugurated (2018). The test case represents an example in which the advanced Geomatics technologies offer multiple challenging outcomes of experimental use of 3D dense models generated by imaging and ranging technologies. In addition to 3d points models, the two-dimensional architectural representation results at different scales will also be briefly discussed.

Keywords: UAV Photogrammetry, SLAM (Simultaneous Localization and mapping) technologies, 3D models, point clouds, accuracy, multiscale models.

I. INTRODUCTION

Archaeological studies have long shown interest in technological innovations for the documentation of the territory and excavations, aiming at the benefits both in terms of knowledge and for the communication and dissemination of the results of the investigations.

This interest is recognizable across the study scales that archaeological research embraces. Starting from the landscape Archeology that since the 80s and 90s has turned to remote sensing and GIS tools [1, 2], up to the site archeology scale and to the study of the findings of excavation, that benefited from the innovations of 3D surveying, making use and stimulating the image and range based survey applications, i.e. photogrammetric and terrestrial laser scanning.

As known, also the UAV photogrammetry (Unmanned Aerial Vehicle), which is considered today one of the main methods of rapid mapping, has undergone a very wide exploitation in various application fields among which archaeological sites are also highly relevant. [3]

This high confidence is due to the aerial point of view that has always played a decisive role in the archaeological survey, so that before the diffusion of photogrammetry from UAVs, aerial shots from braked balloons and kites were already tested. [4, 5]

The wide availability of survey methods that lead to obtaining dense, accurate as well as spatially referenced models, has also favored the development of methods for the structured management of the acquired information, from which have arisen proposals for systems that favor the connection and the capacity to manage both geometric and semantic information in an integrated form. Therefore developments of 3DGIS are derived [6], in addition to systems that enable the analysis and navigation of models that can be explored in the web even in collaborative way [7], and information systems based on standards and ontologies to facilitate the relations between semantic values and models allowing in-depth analysis. [8]

This contribution focuses on the multi-sensor integration of survey techniques and on the multi-scale and multi-resolution models generation, which allows to better meet the needs of reading and interpretation at different scales of the several parts of an archaeological site.

Finally, a further specificity concerns the test case of this contribution: the data acquisition was performed by people of the Geomatics laboratory for cultural heritage of the Politecnico di Torino, while the data processing and the consequent generation of 3D models, were carried out through an educational experience proposed to students in the master degree course in Architecture. That proves that a solid and rigorous workflow leads to appropriate results by allowing a knowledge of the place even from far away.

II. EFFECTIVE RAPID MAPPING METHODS FOR ARCHEOLOGICAL SITE

The multiplicity and the featuring complexity of archaeological objects has made possible to experiment various aerial and terrestrial surveying techniques, aiming at different levels of detail and accuracy, and taking advantage of the low cost and speed of the data capturing phase. These last characters developed for various reasons, not least the needs of fast occupancy of the site in cases of risk and emergencies, attract great favor in the archaeological field and in the general context of cultural heritage (CH), as they are sustainable in terms of mostly economic resources.

Digital photogrammetry, in its close range and UAV arrangements, as well known, has taken its application fortune of recent years thanks to the encounter between the typical algorithms of classical photogrammetry, (internal orientation of the camera, external orientation through direct methods and through the use of Ground control points - GCPs), with the automation and with the ability to derive dense points models typical of Computer Vision algorithms. (image matching and epipolar geometry for the generation of the intersection of homologous rays). [9]

Both the advantages, that is to be able to obtain accurate models, and a workflow that allows programming the level of accuracy in relation to the desired scale of representation before the survey, and the creation of models with a high information content, are particularly valued in the archaeological documentation. This is due both to the fact that the excavation is a destructive study action, and thus to have a model relative to a certain phase of the excavation is particularly important, because the stratigraphic excavation is based among other constrains also on the determination of the levels that characterize the stratigraphic units.[10]

After a first season of professional drones usage, in recent years it has been interesting and has been increasingly proved by wide applications, how much good results for high quality mapping are possible using low cost and widely available drones on the mass market, especially multirotor ones. (An extensive evaluation and comparison of different mapping applications of multirotor drones and their sensor equipment in the sphere of low cost drones can be found in [11])

The main parameters to be taken into consideration during the design phase of the survey using the UAV photogrammetry are the following:

- the scale of the survey: the two large families of drones, fixed-wing and multi-rotor, are distinguished by their flight altitude, flight autonomy and wind resistance. Surely, the use of the fixed wing allows high extension mappings and therefore we can consider in the archaeological context more suited to landscape archeology or to survey scales that embrace entire sites and areas of territory where it is necessary to carry out field archaeological surveys. The multirotor drones are suitable for very different flying heights so they are more effective to fit high and very high scale surveys of excavations sites.
- the flight planning is definitely crucial to get the planned results. First of all, in addition to nadir shots, it is largely available especially in the large scale mapping the ability to acquire oblique shots both through parallel and circular strips (even some fixed wing platform can be equipped by tilting camera. *https://www.sensefly.com/drone/ebee-x-fixed-wing-drone/*). The ability to return accurate models of elevated elements such as masonry, but it is also necessary to consider that oblique images and their different scale with which they represent objects increases the noise of the generated models. Most of the software systems available on the market allow to predefine the ground sampling distance (GSD), i.e. the average size of the pixel on the ground / on the object, which is the usual parameter that allows to estimate in advance the scale of the survey, the accuracy and the level of detail. The conformation of site or objects surveyed have great influence on the flight planning.
- georeferencing strategies and GCPs are needed to assess the global quality of the photogrammetric processing. Although direct georeferencing solutions are available and tested [12], the use of GCPs is certainly the most widespread and it guarantees to evaluate the accuracy of block of images orientation. The number of GCPs can also be reduced due to the conformation of the object of the survey [11] and the different solutions, GNSS / RTK technique or classical using a total station, provide different accuracy results. Therefore for the very high scale documentation of the excavation site and when possible, the classical topographic technique is preferable and the most accurate. [13]

The multi-sensor and multiscale strategies are widespread and highly studied, especially those that integrate image based sensors and terrestrial laser scanning [13, 14, 15]. Among the latter is the emerging technology of mobile scanners based on SLAM algorithms [16], which provide the possibility of obtaining less accurate clouds than the TLS technique, but they are attributable to the technologies that offer rapid mapping, and prove to be extremely versatile in applications to the built heritage. [17, 18]

Pulsed light beams travelling from the sensor to the object and back, are simultaneously aligned during the trip by the registration algorithm implemented in the system and based on 3D SLAM robotics technology [19]. The algorithm works for both the trajectory incremental motion estimation and global points cloud registration along the trajectory.

To close the brief overview of the rapid mapping methods used in built heritage applications or archaeological domain, it is possible to mention that among the most interesting novelties within the close range photogrammetry, multi-camera systems or spherical objectives cameras allow the achievement of photogrammetric applications based on SfM algorithms, starting from the spherical panoramas. [20,21,11]

III. TEST CASE: HIERAPOLIS AT PHRYGIAE

The ancient city of Hierapolis is currently the subject of a PRIN entitled "Archeology of urban landscapes in Asia Minor between late Hellenism and the Byzantine era. Multidisciplinary approaches to the study of Hierapolis of Phrygia."[1] Some of the objectives of the project have been addressed by the Geomatics group of Turin through targeted integrated Geomatic techniques.

The organization of sacred landscapes, the water resources systems, the organization of production and artisan activities have been faced using a balanced use of fixed -wing and high scale multi-rotor drone photogrammetry mapping, integrated

[1] PRIN – Relevant National Interest Project, funded by Ministry of Education, university and Research.

with terrestrial methods, covering from terrestrial laser scanning, to portable solution of ranging and imaging methods.

A. The Ploutonion

Starting from 2008, excavations in the southern area of the Sanctuary of Apollo brought to light a vast monumental complex; the discovery, in 2012, of the dedicatory inscription to Pluto and Kore made it possible to identify definitively the famous Ploutonion of Hierapolis to which the testimonies of numerous ancient writers refer. Remarkable among all that of Strabone (XIII, 4, 14), which refers to a cave from which poisonous vapors come out for the animals that are approaching; in front of the entrance to the cavity there was the sacrifice, by suffocation, of the bulls, with the participation of the eunuchs, priests of Cybele. Cassio Dione (LXVIII, 27) also recalls the presence of a theatron, built above the cave. [22]

The Sanctuary of Hades extends over an area of approx. 2500 square meters, around the cave that opens along the fracture of the fault that crosses the city on the north-south axis, in correspondence of a rock jump of ca. 2 m. The gases come out of the cave, with carbon dioxide in high concentration, and the thermal water that strongly flows from one of the most active sources in the area. [23]

Fig. 1. A nadiral and an oblique view of the Ploutonion site, acquired by drone (L. Teppati pilot).

B. The Nymphaeum of Apollo Sanctuary

The monumental building is located in the central area of the city. It is a complex and stratified group of evidences under investigation. It has been studied and documented for a long time to disclose the dynamics underlying its origins and its relationship with the sacred area devoted to the Apollo oracular cult. Although the nymphaeum was dated to the III century A.D., his origin during a period of intense construction works makes his excavation and study particularly relevant to reconstruct the events of an age of transition to the Christian era. [24]

Fig. 2. A view of the 3D model derived from UAV data of the Nymphaeum of Apollo Sanctuary pertaining the 2018 updating. (Sammartano, Spanò, Teppati data acquisition and processing).

IV. SUITABLE WORKFLOW FOR SPATIAL DATA CAPTURING AND PROCESSING

As usual, a 3D survey planning using integrated Geomatic systems involves an approach that allows to check the final accuracy of results, to compare it with the threshold foreseen for the scale of the architectural complex studied (1: 100).

Given the large scale of the survey sought, the measurement of a series of control points (GCPs) was planned for the following operations:

- to optimize the estimation of internal and external orientation parameters of the photogrammetric block of UAV images, as well as allowing geo-referencing;
- to allow the alignment of LiDAR scans, and to obtain the overall georeferenced cloud in the same reference system as the photogrammetric products;
- to use the overall localized LiDAR cloud, so as to be able to establish the ground truth for referencing the cloud obtained through the Zeb Revo RT mobile mapping system.

The photogrammetric survey has been performed using a DJI Mavic pro multi-copter (camera F220); during the flight, 372 nadir and oblique images were captured at the height of about 40 m (GSD equal to 1cm) (fig.3). Eleven GCPs were used to optimize the interior and exterior orientation of the bundle block adjustment with a total root mean square error RMSE of 1.18 cm, and a final control of the alignment have been accomplished using ten Check Points CPs providing a total RMSE equal to 3.1 cm. (Tab 1), (fig. 4 shows the dense cloud). (Metashape software)

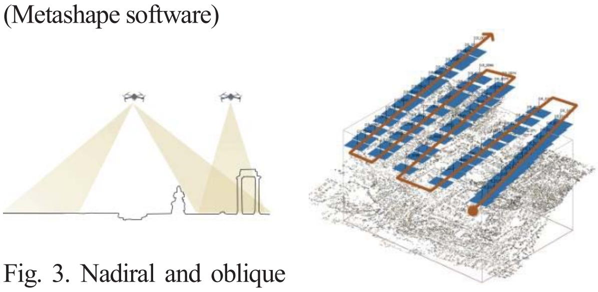


Fig. 3. Nadiral and oblique images capturing and orientation.

Table 1. Total RMSE of GCPs and total RMSE of CPs.

Conteggio	errore X (cm)	errore Y (cm)	errore Z (cm)	errore XY (cm)	Totale (cm)
11	0.799057	0.631832	0.599664	1.01868	1.18207

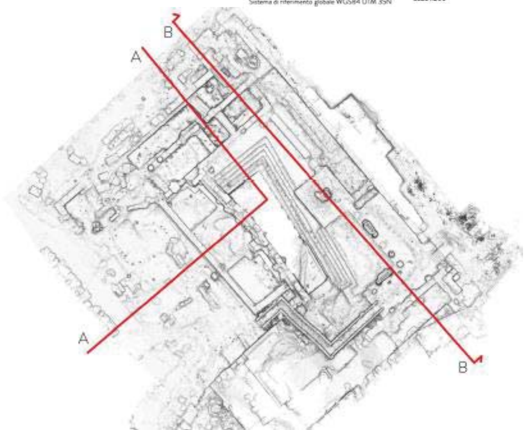
Conteggio	errore X (cm)	errore Y (cm)	errore Z (cm)	errore XY (cm)	Totale (cm)
10	1.09527	2.55694	1.48391	2.78165	3.15271

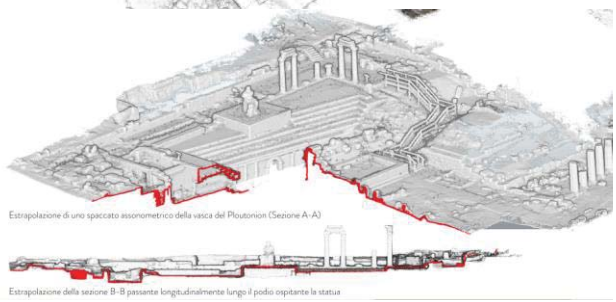
The TLS survey have been performed using the shift phase Faro Focus X330 scanner, acquiring eleven scans well distributed in the area of the Ploutonion. Even the registration results for the TLS survey are good, since the preliminary cloud to cloud registration, performed by the software using an ICP – Iterative Closest Points algorithm, has provided a total error of about 3mm, while the final target based registration provided a RMSE of 8 mm.

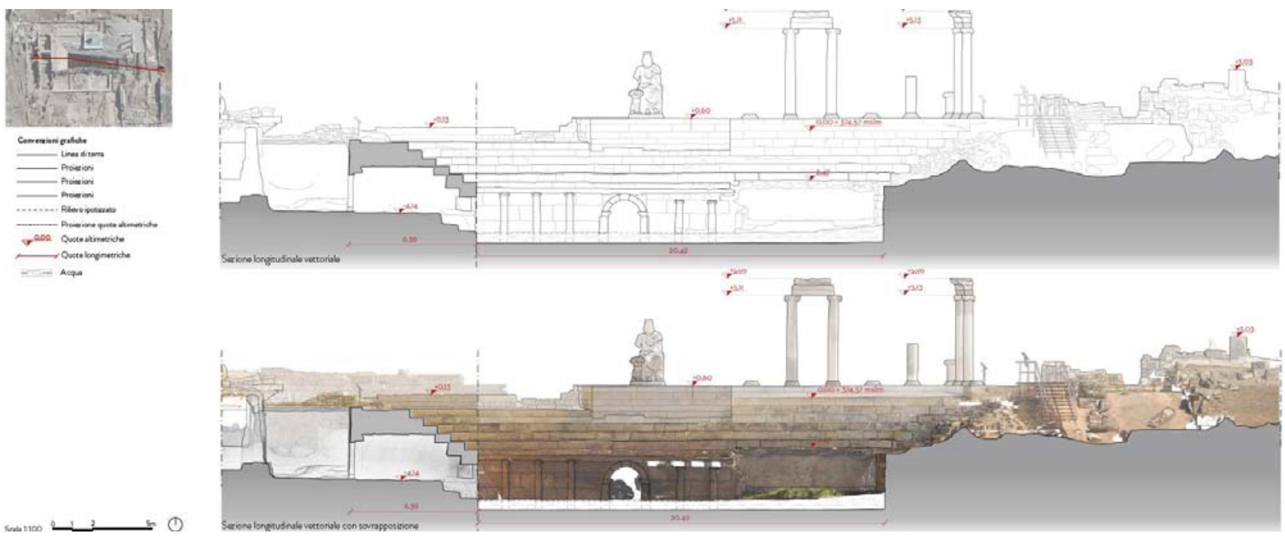
The last type of geomatic survey has been carried out using the laser-based sensor ZEB Revo Real Time (RT) by Geoslam which is a portable MMS-*Mobile Mapping System* working with a Hokuyo UTM-30LX-F scanner technology and using a SLAM algorithm and an *Inertial Measurement Unit* (IMU). The Zeb Revo scanner proved to be very favorable in the area of Ploutonion which is articulated, multilevel, sometimes narrow, and it presents an underground passage (the one used to conduct the bulls to the entrance of the hell with the poisonous vapors, which is visible in the left part of figure 4).

Zeb scans have been captured using roundtrip loops, in order to provide constrains able to reduce the influence of drift errors, and to obtain better post processing optimization of the cloud. The system doesn't provide positioning information so the cloud has been registered using ICP approach wit the UAV cloud, offering an integration of range information to the previous points models, from which the vector and image data featuring the architectural drawings has been carried out. (fig. 4).

Fig.4. (below) Architectural section drawings derived from integrated techniques
Fig. 5 (next column, above). UAV orthophoto.
Fig .6 (nex column, below) Plan view and vertical section of SLAM based mobile mapping points cloud.



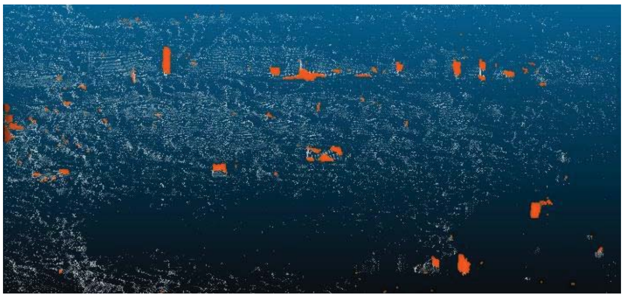




V. PERSPECTIVES. USING CONSOLIDATED TECHNIQUES WITH NEW APPROACH.

The presented case study shows that the current consolidated workflow for the integration of aerial and terrestrial clouds, image and range based, is established on rigorous approaches so that a class of students who did not participate in the field survey can process the data. The advantage of being able to dispose of clouds rich in geometric and radiometric information, makes it possible to remotely analyze the object, which although complex and articulated can be represented by architectural drawings even by operators who have not visited the sites directly.

As perspective, it is possible to highlight that the versatility of methods and algorithms prefigures that in the future more and more tools born for certain purposes can be exploited in other scenarios that will operate with the veracity of point clouds. As an example, we can quickly present an application of the Cloth Simulation Filter (CSF) algorithm proposed by [25] for aerial LiDAR data and implemented in the Cloud Compare software, in the case of terrestrial TLS scans.



Figg. 7-8 The stenopos D (below) captured from 200 meters distance scan position and detected and segmented by the CSF algorithm (above).

Taking advantage of the remarkable size of the Focus X330 scanner, a very high resolution scan (0.009 °) was performed taking up the southern portion of the city of Hierapolis; in this area there are few large buildings and the network of only partially excavated roads can be identified by the presence of low beams or jambs that rise in the underbrush. The application of the CSF algorithm (parameters: cloth resolution 1m; iterations 1000; class.threshold 0.3m) has made it possible to trace and segment the archaeological remains that identify the presence of roads. Figure 7-8 show blocks and jambs that identify the stenopos D, which from the southern area of the city led to one of the theater entrances.

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Fig. 9. (below) *Two frames from the video presenting a multi-temporal representation of the Nymphaeum of Apollo Sanctuary (the reconstruction superimposed on the points and meshed models has been elaborated from the proposal by De Bernardi, 1987 – [26])*