High resolution orthophotos and a digital surface model of the Roman city of *Pollentia* (Mallorca, Spain) using RPAS imagery, aerial images, and open data archives

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***Abstract*—This communication presents an approach to generate high resolution orthophotos and a digital surface model combining RPAS imagery and ground control support derived from aerial and publicly accessible data instead of organizing a specific surveying campaign. The scope of the presented research is the multi-resolution geospatial data management and this research seeks to contribute to this topic by assuring geo-referencing consistency between RPAS imagery and aerial and historical orthophotos. The approach has been experimentally tested and validated in the Roman city of *Pollentia* (Alcúdia, Mallorca, Spain) and might be further applied to any other archeological site where aerial imagery and auxiliary data are available.**

Keywords—geomatics, orientation, GIS, RPAS, Pollentia

I. Introduction

Latest advances in Remotely Piloted Aircraft System (RPAS) technology, Commercial-of-the-self (COTS) miniaturized cameras, and photogrammetric software have allowed the archeological community the access to this technology beyond research and experimental projects [1,2,3]. Recent works have shown the potential and utility of the outputs of these technologies (orthophoto, point clouds and Digital Surface Model (DSM)) for the management of archeological sites, both for documenting and a 3D modelling perspective [1,4,5]. Thanks to the capability of flying at low altitudes, dense point clouds and orthophotos with a high level ground sampling distance (GSD) of a few centimeters can be generated, increasing the quality provided by satellite (meter level) and aerial imagery (decimeter level) [6]. This increased resolution may allow to digitalize an archeological site to a stone level [1,6] or provide detailed scale of the structures, becoming these outputs a suitable alternative to total stations by relaxing requirements in terms of metric accuracy. Moreover, these technologies may also help to detect potential archaeological buried remains when multispectral orthophotos are generated. The advantage in this case is the capability to acquire data in the optimal time window for detecting soil or cropmarks [7].

From an archeological perspective it is important to have historical data, acquired during many years, properly geoferenced and co-registered. That is, it is important to have high resolution orthophoto and DSM, but they might be meaningfulness if there are not properly registered or aligned among multiple temporal acquisitions or with aerial orthophotos archives such as the ones provided by the Spanish PNOA program. The PNOA (*Plan Nacional Ortofotografía Aérea)* is a national program lead by the National Geographic Institute for generating and making publicly available high resolution orthophotos and a Digital Terrain Model for entire Spain, updating them every 2-3 years. The program also provides access to raw imagery and auxiliary data used to generate the aforementioned products.

The orthophoto and DSM generation standard workflow includes the following steps: aerial triangulation, point cloud and digital surface model generation and finally orthophoto generation. Although, the aerial triangulation step involves the estimation of exterior orientation (position and orientation) parameters as well as camera calibration parameters, using homologous, exterior orientation observations provided by on board GNSS receiver and Ground Control Points (GCP) surveyed with differential or RTK GNSS techniques [8], it may happen that resulting orthophoto and DMS are non-proper registered with the aerial cartographic archives. Thus, an additional step may be required to register multiple temporal and multi-resolution orthophotos using an affine or projective model. This step however might be more difficult or not possible with the DSM due to difficulty of identifying common points.

Alternatively, several solutions have been proposed to deal with the co-registration of multi-temporal datasets during the orientation step, prior to orthophotos and DMS generation [9,10]. Both solutions focus on the automatic detection of common points between RPAS datasets or between RPAS and aerial datasets, but differ in the way in which the ground control information is generated. In [9], the image orientation step is performed initially for a reference dataset. Then some images in such dataset are used as anchor images to constrain the orientation step of the remaining images without using ground coordinates of common points. [10] uses planimetric coordinates of common points extracted from available orthophotos and height component from Digital Surface or Digital Terrain Models (DTM).

In this paper, we present an approach to generate high resolution orthophotos from RPAS imagery and DSM avoiding the use of GCPs measured with GNSS techniques, still being able to co-registration between aerial archives orthophotos and RPAS imagery. The innovation of the approach is to avoid the use of GNSS based ground control points and replacing them by GCP derived from aerial imagery and exterior orientation data. Note also that these data were the ones used to generate open and broadly accessible aerial orthophoto archives (PNOA). The key point of the approach is the capability to use reliable ground control points triangulated from aerial images used to generate aerial orthophotos, instead of using coordinates of several GCP surveyed with RTK techniques, potentially lowering the surveying cost. With this approach, the RPAS orthophotos, as well as the DSM, will be co-registered with the PNOA orthophotos and avoiding extra co-registration steps.

II. PROPOSED APPROACH

The proposed workflow includes several steps. The first one is the generation of GCP. In this approach, the GCP are points observed both in aerial and RPAS imagery. The coordinates of these points are obtained using image triangulation techniques instead of deriving the ground coordinates of these points from the planimetric coordinates of the orthophoto and the height from the DSM. This can be done in this way because the exterior orientation of aerial archives as well as camera calibration data are already open and available to anyone upon request. Although the planimetric coordinates of the points derived from the orthophotos are very good (25 cm resolution GSD in the PNOA program), we use this approach because it provides better estimates of the height component than the ones provided in the DTM. Open and available DTM (also from PNOA) provides height in a grid of 5x5 m.

The next step is the aerial triangulation of RPAS imagery involving the following observations: image coordinates of homologous points between images, initial orientation provided by a GNSS and image and ground coordinates from GCP. The exterior orientation of every image as well as the camera calibration parameters are estimated using a bundle adjustment approach. The next steps, common in many photogrammetric software, involve the dense point cloud, DSM and orthophoto generation.

The proposed approach presents several advantages: first, the capability to fuse multi-temporal and multi-resolution datasets to obtain a historical perspective of the archeological excavations. This is done thanks to integrating all data available in a common georeferencing frame. The second advantage is that the proposed approach can be used with no modification of the structure-from motion SWs pipelines. The third advantage is the capability to have centimetric precision (less than 10 cm), allowing the clear identification of the different elements composing an archeological structure, instead of the general form that can be observed from aerial orthophotos. Another advantage is that with the proposed approach, the georeferencing accuracy of the PNOA orthophotos are kept while the resolution might be increased to few centimetres depending of the camera used and flight altitude.

The methodology has been tested and validated in the Roman city of *Pollentia* with the aim to be extended to other Roman settlements.

III. CASE STUDY: POLLENTIA

Pollentia is located at the city of Alcudia, in the island of Mallorca (Spain). The ancient city was identified in the 19th century and continuous excavations have been carried out since 1923. Excavations have uncovered a residential area (Sa Portella), a theatre, part of the forum, several necropolises, and other remains of the city (Figure 1). Nevertheless, several areas are still covered and potential buried remains might be located also in the nearby fields beyond the current limits of the Roman city [11,12].

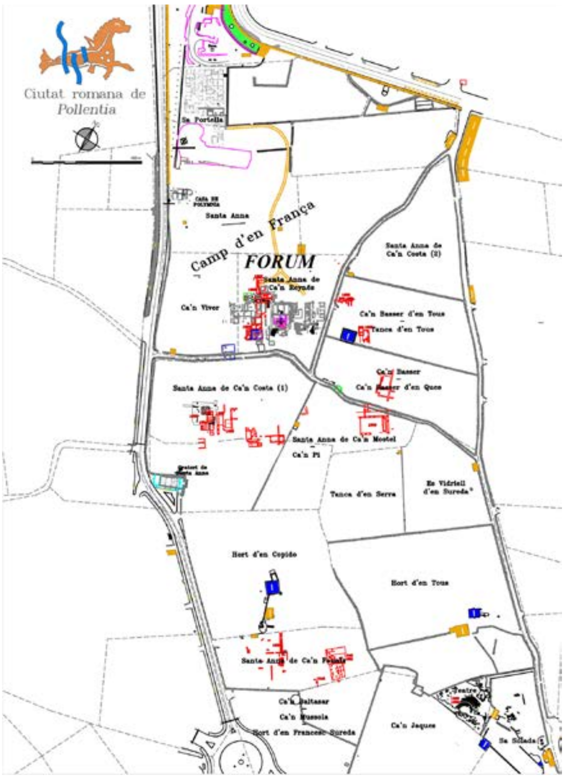

Fig. 1. Map of the Roman city of Pollentia (Source [11]).

A. Datasets

The datasets include PNOA aerial archives and RPAS imagery. Regarding the aerial archives, three different overlapped aerial images, used to generate the 2015 PNOA orthophoto of the area together with the exterior orientation and camera calibration values, were available. The 4-band images acquired with a high-performance metric aerial camera (Vexcel UltracamXP) were taken from a flying height around 2800 m, providing a GSD of 21 cm. The RPAS imagery were acquired with a Micasense RedEdge multispectral camera that was flown in a fixed-wing RPAS over the Roman city of *Pollentia* and nearby fields. 150 images were collected in a flying height of 230m, corresponding to a GSD of 10cm. No laboratory camera calibration was available beyond the information provided in the EXIF file.

B. *Experimental Results*

From the aerial archives, 33 points covering *Pollentia* and its surroundings were selected and their coordinates were triangulated using image coordinates, the exterior and interior orientation (Figure 2). 11 of them were used as GCP while the remaining have been used as checkpoints (CHP) to evaluate the quality of the RPAS imagery aerial triangulation step. The Agisoft Photoscan software was used for performing this task using the ground and image coordinates of the GCP, image coordinates from homologous points together with initial orientation of the images provided by the on-board GNSS receiver of the camera. The image coordinates of the GCP and CHP were manually identified in the RPAS imagery. The ground coordinates of the GCP were input with a very low standard deviation to constrain the bundle adjustment. Camera calibration parameters (focal length, principal point, radial and tangential distortions) were also estimated by the adjusment.

Fig. 2. Distribution of ground control (blue dots) and check points (red triangles) around the Roman city of Pollentia (green area) and nearby fields.

The analysis of the CHP residuals was to the tool to evaluate the quality of the aerial triangulation These checkpoints residuals show a planimetric error better than 1 GSD and slightly higher than 1 GSD for the height component.

Orthophoto and DMS were also generated with the same photogrammetric SW. After the orthophoto generation, some structures belonging to Sa Portella area were manually digitalized into a vectorial layer to be able to check visually the co-registration between PNOA orthophoto and the RPAS orthophoto. Figures 2 and 3 show the geometric consistency of both datasets.

Fig. 3. Detail of Sa Portella area from most recent PNOA orthophoto and digitilized structures (red) from RPAS orthophoto.

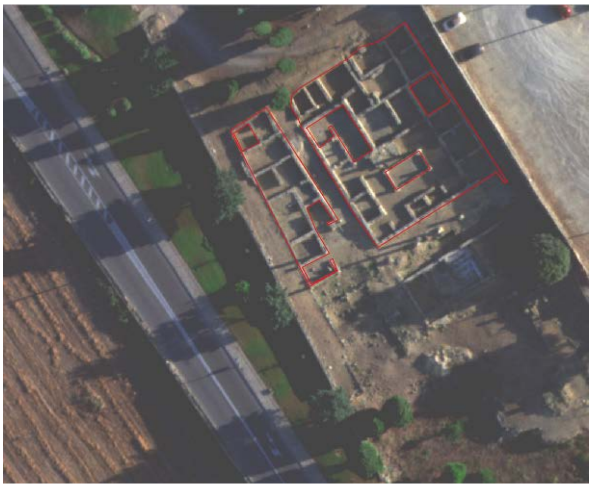

Fig. 4. Detail of Sa Portella area from RPAS orthophoto and digitalized structures (red).

IV. CONCLUSIONS

An approach to assess not only the proper geoferencing of high resolution cartography generated with RPAS imagery but also the multi-temporal co-registration using available aerial georeferenced imagery has been presented. The approach has been tested and validated with RPAS and aerial imagery of *Pollentia*. The aim of this work was not to assess the potential of RPAS imagery, for monitoring and documenting the site, already known by archeological excavations or remains, but to assess the proper integration/fusion with the available historical georeferenced data.

REFERENCES

[1] Campana, S. Drones in Archaeology. State-of-the-art and Future Perspectives. Archaeol. Prospect. 2017, 24, 275–296.

[2] Nex, F. and Remondino, F. (2013) UAV for 3D Mapping Applications: A Review. Applied Geomatics, 6, 1-15.

[3] Opitz, R. and Herrmann, J. (2018) Recent trends and long-standing problems in archaeological remote sensing. *Journal of Computer Applications in Archaeology*, 1(1), pp. 19-41.

[4] Cowley, D.C.; Moriarty, C.; Geddes, G.; Brown, G.L.; Wade, T.; Nichol, C.J. UAVs in Context: Archaeological Airborne Recording in a National Body of Survey and Record. *Drones* 2018, *2*, 2.

[5] Lo Brutto, M., Garraffa, A., Meli, P., 2014. UAV platforms for cultural heritage survey: first results. ISPRS Ann. Photogramm. Remote Sens. Spatial Inf. Sci., II-5, pp. 227-234. doi: 10.5194/isprsannals-II-5-227-2014.

[6] Nikolakopoulos, K.G., Soura, K., Koukouvelas, I.K., Argyropoulos, N.G., 2016. UAV vs classical aerial photogrammetry for archaeological studies, Journal of Archaeological Science, In Press, Available online 20 September 2016.

[7] Masini, N, Marzo, C, Manzari, P, Belmonte, A, Sabia, C and Lasaponara, R.2018. On the characterization of temporal and spatial patterns of archaeological crop-marks. Journal of Cultural Heritage

[8] Lo Brutto, M., Sciortino, R., and Garraffa, A.: RPAS and TLS techniques for archeological survey: the case study of the archeological site of Eraclea Minoa (Italy), Int. Arch. Photogramm. Remote Sens. Spatial Inf. Sci., XLII-2/W3, 433-438, https://doi.org/10.5194/isprs-archives-XLII-2-W3-433-2017, 2017.

[9] Zhuo, X.; Koch, T.; Kurz, F.; Fraundorfer, F.; Reinartz, P. Automatic UAV Image Geo-Registration by Matching UAV Images to Georeferenced Image Data. *Remote Sens.* 2017, *9*, 376.

[10] Aicardi, I.; Nex, F.; Gerke, M.; Lingua, A.M. An Image-Based Approach for the Co-Registration of Multi-Temporal UAV Image Datasets. *Remote Sens.* 2016, *8*, 77

[11] Cau Ontiveros, M.A., Van Strydonck, M., Boudin, M., Mas Florit, C., Mestres, J.S., Cardona, F., Chávez-Álvarez, E., Orfila, M., 2016. Christians in a Muslim world? Radiocarbon dating of the cemetery overlaying the Forum of Pollentia (Mallorca, Balearic Islands). Archaeol. Anthropol. Sci.

[12] Ranieri, G., Godio, A., Loddo, F., Stocco, S., Capizzi, P., Messina, P., Orfila, M., Cau, M.A., Chávez, Mª.E., 2016. Geophysical prospection of the Roman city of Pollentia, Alcúdia (Mallorca, Balearic islands, Spain). J. Appl. Geophys. 134, 125–135.