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BLK2GO for DTM generation in highly vegetated area for detecting and documenting archaeological earthwork anomalies

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Abstract **– This paper illustrates a 3D survey performed at the well-known "Villa di Domiziano" site in the Circeo National Park using the new Leica Mobile Mapping System (MMS) BLK2GO. The project's aim is to identify and document earthwork anomalies, a type of evidence extremely frequent in the Villa, but difficultly traceable both for site's extension and for the presence of mixed vegetation, composed of dense foliage of maritime pines and brushwood. This research, realized within the project "The Domitian Villa: An Imperial Residence in Sabaudia, Italy", winner of the 2019 Grant for the "Shelby White and Leon Levy" program, aims to create a multidisciplinary documentation of the entire Villa of Domitian, starting from the extraction of Digital Terrain Model (DTM). The Test-case was an opportunity to test both practicality and accuracy of new Leica BLK2GO with the ultimate aim of identifying and documenting earthwork anomalies and comparing obtained data with those coming from a previous UAV-LiDAR survey.**

I. INTRODUCTION

Surveying, identification and documentation of archaeological anomalies in a heavily vegetated area is a well-known issue for the three-dimensional survey technologies, both during data acquisition and for subsequent post-processing phases. In some recent literature it is heavily remarked the use of some three-dimensional detection technologies capable of achieving excellent results, mostly in environments with homogeneous and low-density vegetation. The Airborne Laser Scanning (ALS, also referred to as airborne LiDAR), for example, is a widely used data acquisition technology for topographic modelling, that revolutionized prospection of forested areas in archaeology [1; 2] as well as in other fields. The use of ALS, or UAV-LiDAR, for the documentation of archaeological anomalies is nowadays a widespread approach, especially for environments with a medium - low vegetative density, and for large survey areas [3; 4; 5]. Sometimes ground resolution occurring with this kind of acquisition is insufficient for identification and, above all, documentation of archaeological anomalies.

This can happen essentially because of geometric reasons, such as shadow cones due to strong differences in terrain altitude, because of the vegetation, whose excessive density does not allow a sufficient percentage of laser impulse to pass through trees or low bushes and reach ground, and/or because of instrumental deficiency, determined by the insufficient resolution of the sensor or by the flight altitude [6]. To overcome resolution and distance problems, some studies propose the use of ground-based 3D scanning equipment such as a TLS (Terrestrial Laser Scanner) [7]. The use of this instrumentation in forested areas has the drawback of longer acquisition times and problems in the alignment phase due to the noise produced [8], for example, by the movement of vegetation for natural causes, including the wind. In order to investigate buried structures, a further increasingly widespread approach in archaeological research over the last decade is the use of geophysical surveying. These kinds of techniques aim to investigate, with an ever-greater degree of precision, the presence of buried structures and to establish a possible reciprocal spatial correlation. The large-scale applications of these non-invasive methods has a great potential, which, however, can hardly be expressed at his best in a forest environment, due to the presence of trees and their root systems. This method, that could offer an appropriate solution and provide valuable analytical information on archaeological anomalies, requires however implementation and adherence to the highest technical and instrumental standards, as well as imposing long times for acquisition, post-processing and interpretation [9]. A further application of ground-based surveying technologies in forest environment is illustrated in recent scientific literature: the use of Wearable Mobile Mapping System (WMMS) [10]. This method, for articulated routes such as those in forest, has significant advantages indeed: speed in data acquisition, portability of the instrument and, in our case, appropriate accuracy for the purposes of documenting the earthwork anomalies. The use of WMMS systems can in fact produce metric designs that conform to the representations of archaeological anomalies or architectural evidences even in a wooded environment and on an estimated scale, even in the worst conditions of visibility, between 1: 200 and 1: 500 depending on the complexity of the paths to follow to achieve an adequate graphic representation [11]. The case study presented focuses on addressing some critical issues, both in the acquisition phase and in the post-processing one of the data acquired in a forest environment, to document earthwork anomalies. The "Villa di Domiziano" is in fact characterized by the dense presence of maritime pines, trees between 30 and 40 m high with dense needle-like foliage. The density of maritime pines is such that only a few recently excavated areas are visible from the top (Fig. 1). As a consequence of these very difficult visibility conditions, for the identification and mapping of archaeological anomalies, also in consideration of the dense forest, an integrated remote sensing campaign was designed, systematically using all the latest technologies for three-dimensional survey.

In particular, for areas with significant presence of feature and earthwork anomalies, after a LiDAR acquisition, a subsequent thickening of the scan data was carried out by means of MMS technology. In fact, especially while surveying articulated territorial contexts, the use of a single type of acquisition system rarely allows the return of a multi-resolution model, such as to satisfy all documentation needs, and therefore with scales varying from architectural - 1:100 - to territorial - 1:500 [12]. The MMS system chosen for this increase in the level of detail, implemented in an area densely packed with archaeological anomalies - the "Area delle Cisterne" -, is the brand-new Leica's instrument, the BLK2GO in its first product release version. For accuracy, density and completeness evaluation of data coming from BLK2GO, some comparisons were carried using significant homologous sections fromUAV-LiDAR survey.

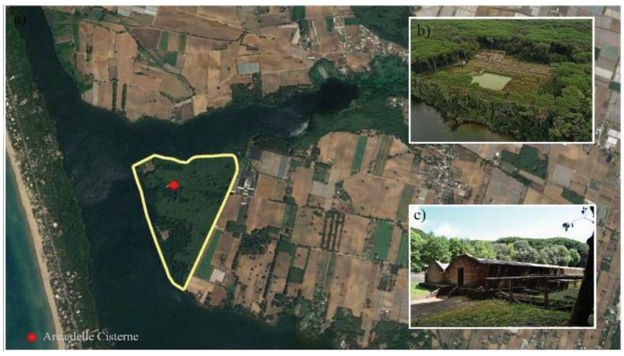

Fig.1: (a) location map; (b) UAV oblique image of the vegetation on the Domitian Villa; (c) the "Area delle Cisterne".

II. PROJECT AND TEST AREA

The MMS acquisition presented in this paper is part of the "The Domitian Villa: An Imperial Residence in Sabaudia, Italy" project, winner of the 2019 Grant for the "Shelby White and Leon Levy" program. The aim of this project is the realization of a complete edition of the Domitian Villa, including unpublished excavation, already explored structures and archaeological materials. For the identification and mapping of the anomalies that buried structures left on the site's surface (46 hectares), an acquisition has been designed integrating the systematic use of all the latest survey three-dimensional technologies. In particular, this paper illustrates a test case concerning a UAV-LiDAR application for the entire archaeological area and the subsequent thickening of data by means of MMS technology only for the "Area delle Cisterne". This area is characterized by the presence of emerging structures and evident earthwork anomalies covered by both tall (maritime pine) and low (bramble bushes) dense vegetation. The "Area delle Cisterne" seems destined for water storage since the earliest stages of the site's occupation (beginning of the 1st century BC). This functional destination of the area becomes certain in during the third constructive phase (first half of the 1st century AD), when two huge cisterns were built: the "Cisterna dell'Eco" and the "Cisterna di Raccolta". These two cisterns were connected to the oldest water supply system through new collectors. The test area is located just south of the "Cisterna dell'Eco". The close relationship of the area under investigation with the cistern is underlined by an underground corridor.

III. EQUIPMENT

The BLK2GO is a small (dimensions about 28 x 8 cm, weight about 800 g) dual axis LiDAR (both axes constantly spin while scanning), enclosed in a fully protected and encapsulated dome with scan velocity of 420.000 points/s. Its core technology, called by the manufacturer "The GrandSlam", is based partially on the SLAM (Simultaneous Localization and Mapping) technology, simultaneously combining high-speed dual axis LiDAR, multicamera vision system and an inertial measurement unit that makes the BLK2GO self-navigating. The Multicamera Vision System, not yet available in the first product release version, will soon include an integrated camera with a sensor of 12 megapixel (field of view 90° x 120°), plus three panoramic cameras (4.8 Mpixel, field of view - 300° x 135°, global shutter) for visual navigation via SLAM. Captured images make it possible to generate a point cloud with RGB attribute. Scanning is started by a single button on the laser case, while the BLK2GO Live app allows at once to view essential data while scanning, device status and file storage management. The connection between the controlling device and the laser unit is wireless. The handheld laser has an acquisition range between 0.5 - 25 m, with declared local accuracy between 6 - 15 mm. To improve self-registration during data acquisition it is preferable to make closed paths, such as a circle. The initial scanning point and the final point are marked by the same "docking base", useful in order to optimize cloud registration and reduce alignment error (Fig. 2). The Leica BLK2GO used for the test case, still in the first product release version, had the Multicamera Vision System deactivated, therefore in the acquisition phase the instrument can be assimilated to the typical functioning of a MMS.

IV. DATA ACQUISITION

This research aims to propose a procedural workflow for data acquisition and management in order to test the effective possibility of using MMS for the accurate extraction of DTM from point clouds in order to identify and document earthwork anomalies.

In this regard, it is possible to identify a succession of activities that characterize this type of acquisition: (i) survey design (path planning); (ii) data acquisition (protocol and basic rules); (iii) data alignment and post-processing (alignment and vegetation filtering); (iv) DTM extraction and subsequent generation of cartographic products (from 3D digital models to 2D graphic representation). Figure 3 illustrates the proposed procedure workflow.

For these reasons, it is useful to define a series of operational rules for forestry survey: (i) inspect the site in advance in order to remove any obstacles along the path (scrub, felled trees, etc.); (ii) walk slowly during the scanning phase to have a better coverage between the data and a higher resolution (in fact, with a fast pace, there may be a minimum non-redundancy of the data such as to prevent the alignment of the point cloud); (iii) proceed as slowly as possible in the presence of strong vegetation in order to allow the best possible alignment and data redundancy; (iv) pay attention to transition areas avoiding sharp curves which have to be crossed slowly; (v) divide long paths into more than one scan mission both to avoid large point clouds and to minimize the drift effect and therefore propagation of alignment errors; (vi) acquire large common areas between successive scans, so as to be able to evaluate eventual misclosure.

The acquisition of “Area delle Cisterne” consisted of 4 walks: Walk n.1, about 75 m long, runs along a stretch in a south-east direction (red path). Walk n. 2, with a circular shape, goes around the “Area delle Cisterne” and is about 385 m long (yellow path). Walk n. 3 was created to refine the data collected in an area characterized by the significant presence of anomalies, such as to require a further passage about 75 m long (green path). Walk n.4 involves a path inside the villa, a modern fire escape route, about 200 m long (blue path).

Fig.2: Leica personnel scanning the “Area delle Cisterne” and the Leica BLK2GO with its base.

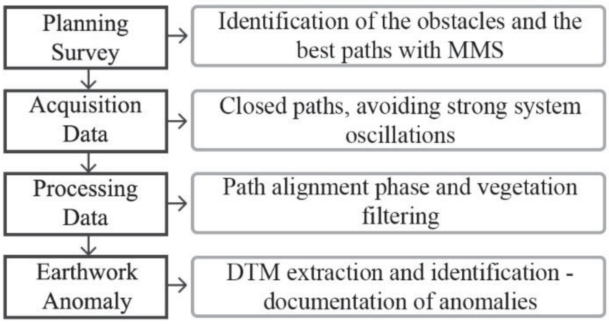

Fig.3: Proposed workflow

The four paths taken are shown in Figure 4.

The various paths length, approximately 700 linear meters of rough and uncomfortable terrain were detected in the area surrounding the cisterns in about 1h and 30 minutes of acquisition.

In order to evaluate the characteristics of the point cloud obtained by BLK2GO, the latter was compared with a UAV-LiDAR cloud previously acquired during the same research project. With UAV-LiDAR technology a total of 50 hectares were scanned in three flights, positioning the take-off point in such a way as to be in VLOS (Visual Line Of Sight) conditions during each acquisition.

Each flight took place in automatic mode using a flight plan. For all the surveys, the UAV was set to a target altitude of 70 m above the take-off point and horizontal ground speed of 3.0 m/s. The height is computed in the automatic flight planning software DJI Ground Station, using elevation data derived from Google Earth.

Parallel flight lines were programmed to have an acquisition front-overlap of 80% and side-overlap of 60%. The returned point cloud contained both the vegetated part - mainly consisting of the crowns of the maritime pines, their trunks and a few emerged structures and scrub - and the ground.

This point cloud had over 260 million points with a density of approximately 508 pt/m.

V. POINT CLOUD POST-PROCESSING AND COMPARISON

Once the MMS scans were aligned using Leica Cyclone 3DR Pro Edition (https://leica-geosystems.com/it-it/products/laser-scanners/software/leica-cyclone/leica-cyclone-register), the ground points were classified using the LiDAR360 software (https://greenvalleyintl.com/software/lidar360/).

The alignment procedure took place through the identification of natural homologous points.

This was possible because, for all the routes, the starting and closing point of the scan were located on the façade of an emerging cistern. The average alignment error on the homologous points identified is about 2.4 cm. It was not possible to improve the alignment using ICP procedures, as the noise in some scans, due to vegetation and some drift effects around the facades, compromised the effectiveness of the manual alignment. The four point clouds were then simply roto-translated in space, with respect to the reference system of the Scan reference - Path n.2.

Once the scans of each single path were aligned, the vegetation was filtered out using LiDAR360 software. The command used for this operation is "Filter Ground Points".

In order to obtain an adequate descriptive result, the following parameters have been set: Grid Size (in our case 0.5 m), Ground Thickness (in our case set at 0.3 m), i.e. the thickness obtained from the lowest point of the point cloud where to search for the ground ones, the Window Smooth parameter (optional), to use neighbourhood grid data to conduct ground point consistency filtering, and the Window Size parameter (in our case equal to 3, the Size of the neighbourhood window 3x3). After filtering a "ground layer", the generated cloud was optimized using a noise filter in order to clean those points located above and below the ground plan. The denoising procedure was performed using the "Noise Filter" command in LiDAR360. The parameters that have been set for the use of the filter are: Radius - the radius of the fitting plane - in our case set as the calculation grid, and Multiples of std deviation parameter, to use the relative error (σ) as a parameter for outliers removal (in our case study value is 1.0). The algorithm automatically calculates the standard deviation (stddev) of a point P'_s surrounding a fitting plane by eliminating P if the distance is greater than σ. In this way it is possible to eliminate the Outliers points applying the Remove Isolated Points parameter, to delete the isolated points when there are less than 4 points within the distance of the searching radius. At the end of the process, the filtered clouds were calculated; the parameters for the original and filtered clouds, for each walk, are summarized in Tab.1.

From the obtained point clouds, DTMs with a grid resolution of 5 cm were calculated.

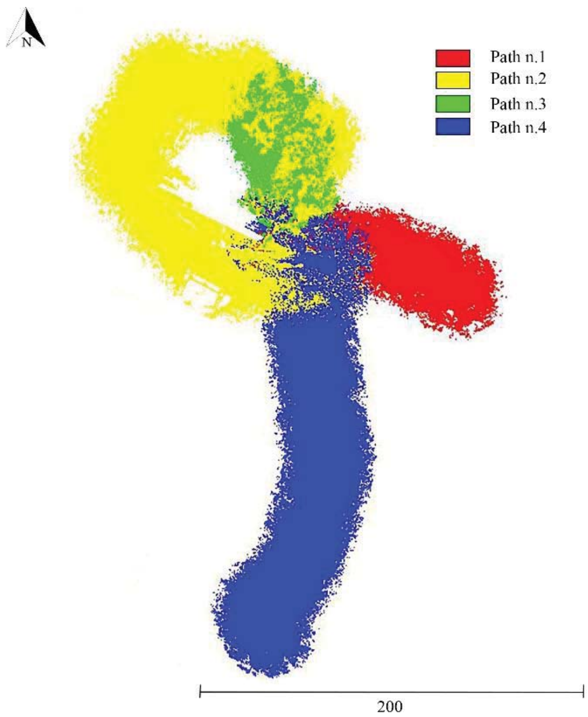

Fig. 4: Representation of the paths walked with the Leica BLK2GO

In Figure 5 it is possible to observe the orthophoto generated from the point clouds by aligning the four paths, both with the presence of vegetation and only with the ground layer. In particular, it can be observed how the process of filtering out the vegetation for the generation of the DTM has cleaned the trees with a good graphic rendering, and in particular the trunks on the ground. It can also be observed how in some areas, where the slopes vary rapidly, following the filtering procedure, a minimum noise remains in the areas heavily vegetated with brushwood. To ascertain the effectiveness of the filtering procedure, it was decided to produce some cross sections along the various paths taken. Figure 6 shows the point clouds cross sections before and after the filtering process, highlighted in red are the ground layer clouds coming from the Leica BLK2GO (average density of the Ground cloud 2561 pt/m). This cross section is compared with the ground layer cloud, in blue, coming from UAV-LiDAR, (density of the ground cloud obtained from LIDAR sensor is of 40 pt/m). As can be seen, the point clouds returned by the Leica BLK2GO, for the camera system present, come together with the RGB information, an advantage of little significance in the forestry field but fundamental for any applications in architecture. In particular, it can be observed that the filtering procedure is effective when the density of the points on the ground is very high, while in the areas where there is a lower density of points - due to the formation of rapid shadow cones during the acquisition - there are gaps of information.

VI. RASTER PROCESSING AND CARTOGRAPHIC PRODUCT GENERATION

For earthwork anomalies documentation, the first step consisted in transforming the terrain point cloud into a raster grid. To do that, the Cloud Compare's Rasterize plugin was used, in order to generate a raster grid with altitude attribute. The size of the grid chosen was 5 cm to limit the noise effect in the final product, the software has also taken steps to interpolate any data gaps with an average value. The GEOTIFF obtained was subsequently imported into the Global Mapper software, creating a random colors palette that highlighted passages of height every 20 cm, thus obtaining a DTM in false colors (Fig. 7). Using this raster image, it has been possible to trace the identified anomalies. From the analysis of MMS data - proven by UAV-LiDAR data - the presence of a rectangular area, measuring about 120 x 200 Roman feet (59 x 34 m), immediately south of the "Cisterna dell'Eco", was identified.

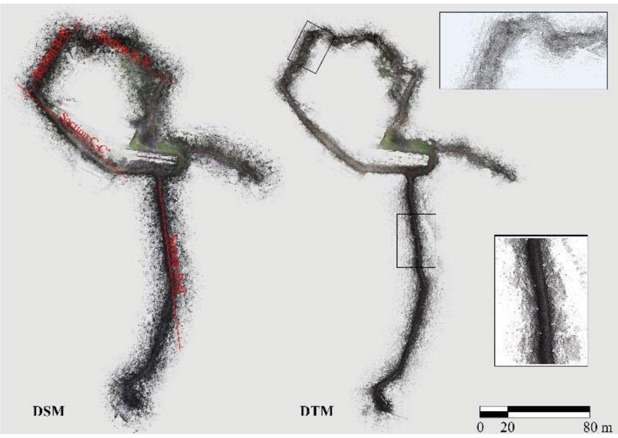

Fig 5: Orthophoto before (left) and after (right) vegetation filtering, and details of the filtering process

Tab. 1: Point cloud features.

Path	1	2	3	4
Number of Points (M.pt)	30.180	97.798	30.108	62.284
Number of Points after Filtering (M.pt)	6.373	22.264	7.638	18.536
Mean Surface Density - before Filtering (pt/m)	6532	6406	5248	4865
Mean Surface Density - after Filtering (pt/m)	2447	2512	2427	1605

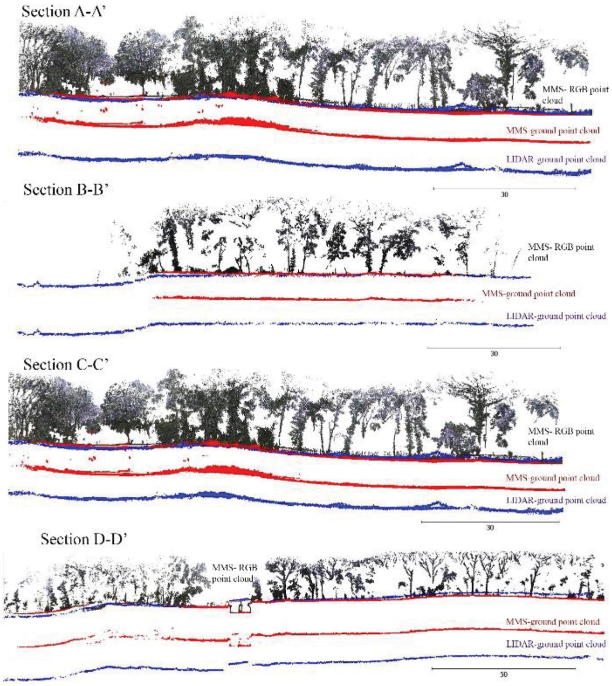

Fig 6: point cloud cross-sections

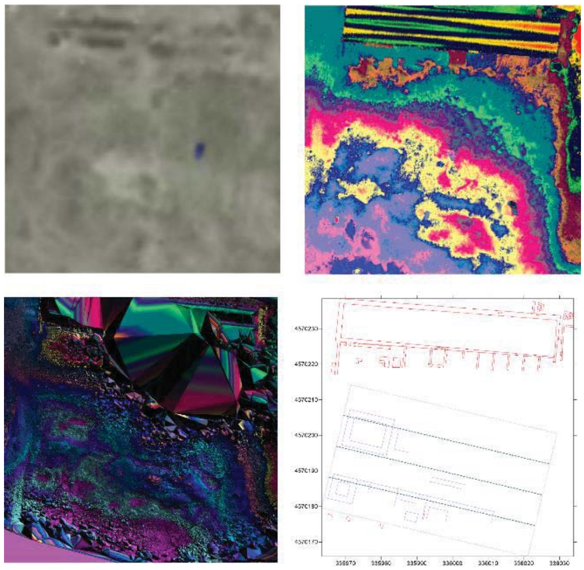

Fig 7: a) Historical air photo b) LiDAR DTM c) MMS DTM d) Anomalies tracing

From the DTM generated with UAV-LIDAR, it was possible to hypothesize the general shape of the structure, while from the DTM created with BLK2GO it was possible to appreciate the internal articulation of the anomaly into different rooms, allowing a summary rendering of the plan of the structure. Following a direct survey, given the presence of structures characterized by parietal tubules, the area was interpreted as a possible thermal complex.

VII. CONCLUSION

The acquisition strategy employing different sensors for the survey of features and earthwork anomalies in conditions of dense vegetation, has led to results that we could define as complementary, namely: the extensive survey with UAV-LIDAR allowed to highlight the presence of buildings and the general organization of the peninsula, limiting the survey, and above all the intensive survey, to the most promising areas, allowing a deepening of the documentation with MMS instrumentation, impossible for the entire extension of the site, only on the most impenetrable or promising areas.

The documentation obtained using the Leica BLK2GO has made it possible to produce, particularly in the areas almost impenetrable to LiDAR, the planimetric articulation of some previously identified buildings, leading, in the most fortunate cases and, in combination with a direct survey, to their interpretation. The study shows also that it is convenient, in areas that are not too extended, and in dense vegetation condition, to document archaeological anomalies, both earthworks and feature, with MMS systems instead of UAV-LiDAR. This procedure has the great advantage of producing a higher density of points on the ground (about 60 times greater), which allows a better identification and documentation of the traces characterized by modest extension or height. In particular, the tested MMS tool, the Leica BLK2GO, having the ability to acquire images to colour the point cloud, suits perfectly for surveying and archaeological documentation, even in purely architectural fields.

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