Generation of 3D Models Obtained with Low-Cost RGB and Thermal Sensors Mounted on Drones

Julio Manuel de Luis Ruiz, Javier Sedano Cibrián, Rubén Pérez Álvarez, Raúl Pereda García, Felipe Piña García

Abstract**—**Nowadays it is common to resort to aerial photography to carry out the prospection and/or exploration of archaeological sites. In recent years, Unmanned Aerial Vehicles (UAVs) have been applied as the vehicles that carry the sensor. This implies certain advantages, such as the possibility of including low-cost sensors, given that these vehicles can carry the sensor at relatively low altitudes. Due to this, low-cost dual sensors have recently begun to be used. This new equipment can collaborate with classic Digital Elevation Models (DEMs) in the exploration of archaeological sites, but this entails the need for a methodological setting to optimize the acquisition, processing and exploitation of the information provided by low-cost dual sensors. This research focuses on the design of an appropriate workflow to obtain 3D models with low-cost sensors carried on UAVs, both in the RGB and thermal domains. All the foregoing has been applied to the archaeological site of Juliobriga, located in Cantabria (Spain). To this end, a flight with this type of sensors has been planned, developed and analyzed. It has been applied to the archaeological site of Juliobriga (Cantabria, Spain). A strong dependence of the thermal sensor on the GSD, and the capability of this technique to interpret underground materials. This research allows to state that the thermal nature of the site does not provide main information about the site itself, but with combination with other types of information, such as the DEM, the typology of materials, etc., can produce very positive results with respect to the exploration and knowledge of the site.

Keywords**—**Process optimization, RGB models, thermal models, UAV, workflow.

I. Introduction

PHOTOGRAMMETRY is a technique that has been usedto obtain representations of the territory. In this sense, it is considered as a discipline related to archaeology, as it allows obtaining the cartographic basis on which the archaeological site is embodied [1]. In recent years, the historical evolution of photogrammetry has been remarkable both in terms of the instrumental and methodological field, and the final product that is generated. If in the 1950s photogrammetry made it possible to obtain the restitution stereo plots from aerial photographs, and therefore the classic analogue cartography, during the following 50 years the procedure was implemented to generate this cartography in digital format and to start working with DEMs. One of the several applications of the DEM focuses on the field of archaeology, where it is possible to evaluate earthworks, dimension excavations, intuit the direction in which a specific archaeological site is evolving according to the elevations and depressions of the terrain, etc.

At the beginning of the 20th century, the appearance on the scene of UAV led to an expansion of the photogrammetric technique [2], mainly due to the simplification of the technique and instrumentation, but above all, due to the drastic reduction in the budget required to undertake a project of this type [3], [4]. Almost any type of sensor can be mounted on this type of vehicle, from the most powerful multispectral sensors [5] to the simplest and cheapest sensors on the market [6]. Hence, the use of low-cost sensors has allowed this technique to expand. In this regard, cameras sensitive to radiations with wavelengths within the visible spectrum (the so-called 'Red, Green, Blue', RGB) were the first sensors to be applied. The height of flight of the drones, and the possibility to develop large overlaps, eliminated the need for metric cameras, which significantly reduced the cost of the sensor. In addition to the foregoing, dual cameras, capable of capturing both the RGB and the infrared or thermal band, have recently started to be used. This research focuses on the analysis of the planning and generation of simultaneous RGB and thermal models with low-cost sensors for archaeological applications. Although the cost is affordable, these kind of uses require a certain methodological approach to obtain the desired product, which justifies this research.

The archaeological site selected to test the proposed methodology is Juliobriga (Fig. 1), a Roman civitas that is located in the south of Cantabria (Spain). Although its exact date of foundation is unknown, 15 BC is commonly accepted. The urbanization process was completed during the 1st century AD, and the city was inhabited until the middle decades of the 3rd century [7].

Fig. 1 Aerial view of the study area of the site

II. Instrumental Proposal and Methodology

A. Instrumental Proposal

Nowadays, there are a myriad of sensors with a wide range of economic possibilities, which can be simply reduced to the following categories: metric, thermal and hyperspectral RGB cameras. The cost of metric cameras is generally high, while

Julio Manuel de Luis Ruiz, Javier Sedano Cibrian, Rubén Pérez Álvarez, Raúl Pereda García and Felipe Piña García are with the School of Mining and Energy Engineering of University of Cantabria, Spain (corresponding author, phone +34 942 846535; e-mail: deluisj@unican.es).

quasimetric cameras are usually low cost. Manufacturers have recently started to produce dual cameras, consisting of a non-metric RGB sensor and an Infrared or Thermal sensor. These cameras are affordable but flight planning must be more careful because the sensor is not metric. In this sense, the sensor chosen for this research should meet all the conditions described above (dual sensor, quasi-metric, etc.) and it should also be economically competitive. After a thorough review of the existing equipment on the market, a DJI Mayic Enterprise Dual quadcopter drone was chosen (Fig. 2). It is a compact drone that allows the user to measure temperatures, and to store RGB and Thermal for efficient reporting and analysis. This drone was developed for professional uses and integrates powerful thermal and visual cameras that make the it a versatile tool for inspection, security, rescue activities, etc. The drone has a light weight and reduced dimensions, which allows a medium flight autonomy, and robust sensor technology. It can fly stably and accurately even in relatively adverse weather conditions, with wind speeds of up to 50 km/h.

Fig. 2 DJI Mavic Enterprise Dual

Table I shows the main features of the device.

TABLE I
DJI MAVIC ENTERPRISE DUAL SPECIFICATIONS

Take-off weight (Without accessories)	899 g
Dimensions (Length x Width x Height)	Folded, 214 x 91 x 84 mm Unfolded, 322 x 242 x 140 mm
Maximum Speed (Ascending)	5 m/s (S mode, without accessories) 4 m/s (P mode, with accessories)
Maximum Speed (Descending)	3 m/s (S mode, without accessories) 3 m/s (P mode, with accessories)
Maximum Speed (Fligth)	72 Km/h (S mode, without wind) 50 Km/h (P mode, without wind)
Maximum Height (Over the Sea Level)	6,000 m
Maximum time of flight (Without with)	31 minutes (Constant speed, 25 km/h)
GNSS	GPS + GLONASS
Accuracy of Steady Flight	Horizontal: 0.5 m Vertical: 1.5 metros
Internal Storage	24 GB

The RGB camera built into the Mavic Enterprise Dual drone is an M2ED visual camera, a true image sensor with 4K resolution to capture visible light. The specific features of this camera are listed in Table II.

TABLE II
FEATURES OF THE MAVIC ENTERPRISE DUAL RGB SENSOR.

Sensor resolution	12 Mp
Focal length	4.5 mm
Lens	FOV: 85º approx. Aperture f/2,8
Maximum image size	4056 x 3040 (4:3) 4056 x 2280 (16:9)
Video mode	4 K Ultra HD: 3840 x 2160 2.7 K: 2688 x 1512 FHD: 1920 x 1080
Maximum bit rate	100 Mbps
Picture format	JPEG
Video formats	MP4, MOV

The images obtained with this sensor are stored simultaneously and automatically with the thermal images captured by the Mavic Enterprise Dual thermal sensor, which is a FLIR Lepton® micro thermal camera. The technical features of this multispectral sensor are listed in Table III.

TABLE III
MAVIC ENTERPRISE DUAL THERMAL SENSOR FEATURES.

Sensor	Uncooled VOx Microbolometer
Lense	HFOV 57º Aperture f/1,1
Focal length	4.5 mm
Resolution	160 x 120
pixel size	12 microns
Spectral bands	8-14 microns
Image size	640 x 480 (4:3) 640 x 360 (16:9)
Scene range	High gain -10 to 140 ºC Low gain -10 to 400 ºC
Picture format	JPEG
Video formats	MP4, MOV

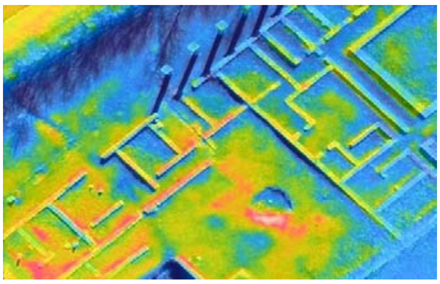
B. Photogrammetric Flight Planning.

Once the sensor has been chosen, the flight that the drone will have to perform must be designed to guarantee that the most appropriate information for the purpose is captured [8]. This justifies the importance of the flight planning within the set of operations that must be carried out to be able to model the terrain, especially when working with low-cost sensors, which require a much more careful methodology in terms of flight height, overlaps, Ground Control Points (GCPs), etc.[9], and most particularly when applying thermal sensors, whose specifications are commonly lower than those of RGB sensors [10], as it happens in this research. In this regard, and considering the technical specifications of the sensors described in Tables II and III, it is convenient to design a photogrammetric flight adapted to the needs of the sensor with the worst performance (thermal), given that if they are programmed for the one with the best features (RGB), the thermal model will have data that are not appropriate for the generation of this model. A number of software packages, which include open source options, can be applied to program the flight quickly and easily, according to the sensor features and the characteristics of the model to be obtained [11]. Before the flight, GCPs must be pre-signaled on the area to be flown so as to be able to carry out the external orientation of the model [12]. To this end, signals specifically designed to be automatically recognized by the software are used. The result of the flight planning and the distribution of GCPs is shown in Fig. 3.

Fig. 3 Flight planning and GCPs

After the photogrammetric flight, the products obtained from the sensor are aerial photographs in the RGB and Thermal bands, which can be seen in Fig. 4.

(a)



(b)

Fig. 4 Images acquired with the diferent sensors: (a) RGB sensor, (b) thermal sensor

In the light of the images obtained with the sensors, the next step is fully developed by using the appropriate hardware and software. In this research, Metashape Agisof has been applied, although there are a multitude of platforms that allow data processing.

III. Results

As a result of image processing, various by-products are obtained. Depending on its purpose, these can be of great use in site modelling. Firstly, all the by-products related to the RGB sensor are obtained, such as the point cloud, the wire mesh, the solid meshes or terrain triangulation, the textured model, the shaded model and finally, the orthophotograph.

Fig. 5 RGB Point cloud

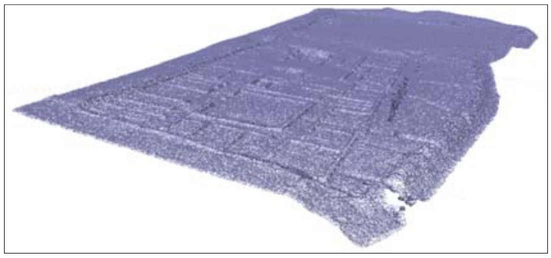


Fig. 6 RGB wire mesh

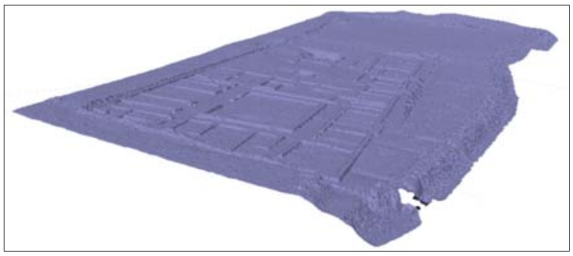


Fig. 7 RGB solid mesh

Fig. 8 RGB model with textures

Fig. 9 Shaded RGB model with textures

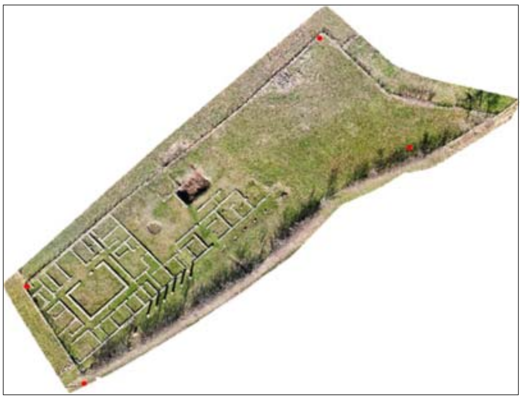


Fig. 10 Ortophotograph

Secondly, all the outputs related to the thermal sensor are obtained. Among these by-products are the point clouds, the wire mesh, the solid mesh or terrain triangulation, the texturised model and the shaded model.

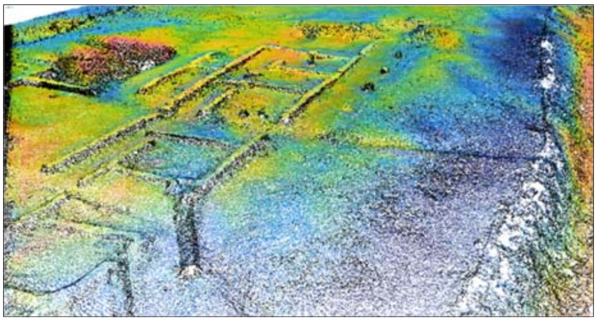


Fig. 11 Thermal point cloud

Fig. 12 Thermal wire mesh

Fig. 13 Thermal solid mesh

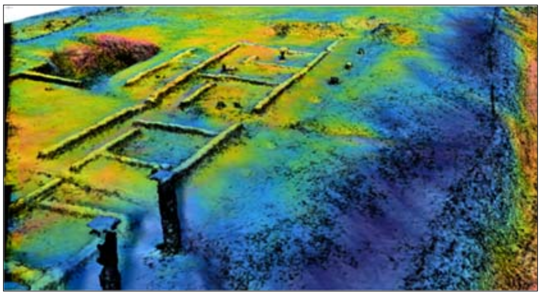


Fig. 14 Shaded thermal model

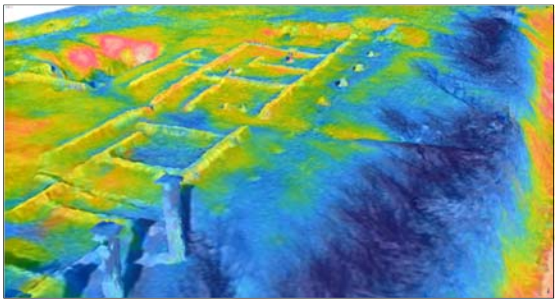


Fig. 15 Thermal model with textures

Needless to say, the number of results supports the potential of this technique, which was unthinkable a short time ago and can now be developed with very little effort.

IV. Discussion

After this research, which is focused on the methodological analysis for the implementation of thermal information with low-cost sensors in archaeology, several possible interpretations of its results are proposed:

- The interpretation of the results of this research suggests that the choice of sensor is one of the most relevant decisions when it comes to obtaining appropriate results. At present, low-cost sensor manufacturers offer two different possibilities: the first option implies using an RGB sensor and a thermal one, while the second alternative involves a dual device that integrates both sensors. This second alternative greatly restricts the number of available sensors. However, it avoids a second UAV flight and guarantees that all the information is acquired from a single flight and, therefore, with the same conditions.
- This research is not focused on the determination of the parameters that define the flight planning. This type of flights, which are intended to obtain more or less conventional results in terms of precision, do not require specific tools for flight planning, and they can be developed with the usual criteria for parameters such as Ground Sampling Distance (GSD), flight height, overlaps, GCPs, etc. Nowadays, there is a wide range of closed and open source software to develop such planning. However, the technical specifications of the most restrictive sensor must be chosen for a correct flight planning.
- The definition of the software to be used is another choice to be made. In this sense, there are different determining

factors that can condition this selection. Aspects such as the costs, or whether the software is open or close source, are considered in the decision-making process, given that the results generated by this type of packages are more or less similar (point clouds, wire meshes, texturized meshes, orthophotographs, etc.).

All these issues are improvable factors and precautions to be considered, and are intended to help future studies aimed at contrasting the generation of thermal models obtained with low-cost UAV-supported sensors.

V. CONCLUSIONS

After analysing the results obtained from the application of the methodological proposal, it can be concluded that:

- Although flight planning does not require specific tools, in the case of the dual sensor, the technical features of the RGB sensor are usually considerably better than those of the thermal sensor. This must be taken into account when designing the flight in order to adequate it to the most restrictive range of technical specifications, which are usually those of the thermal sensor. The rest of the planning can be developed according to the usual criteria for GSD, flight height, overlaps, GCPs, etc.
- Considering the results provided by the software, there is a correspondence between the models generated from the data acquired with the RGB sensor and those captured with the thermal sensor. The data acquired by the RGB sensor are more disseminated nowadays and allow obtaining very adequate DEMs. The data obtained from the thermal sensor, which are less widely used, can provide thermal information on the materials that form the earth crust, and therefore contribute to something as important as the current management of the archaeological site.
- Initially, the thermal character of an archaeological site should not be characteristic or differentiating enough to be able to determine the evolution of an archaeological site, but an adequate combination with an analysis of the DEM and the materials that exist in the site can provide positive results. All the foregoing in intended to obtain more information to support decision making, with very low and perfectly assumable costs.

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