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Application Methodology for the Generation of 3D Thermal Models Using UAV Photogrammety and Dual Sensors for Mining/Industrial Facilities Inspection

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***Abstract*—**Structural inspection activities are necessary to ensure the correct functioning of infrastructures. UAV techniques have become more popular than traditional techniques. Specifically, UAV Photogrammetry allows time and cost savings. The development of this technology has permitted the use of low-cost thermal sensors in UAVs. The representation of 3D thermal models with this type of equipment is in continuous evolution. The direct processing of thermal images usually leads to errors and inaccurate results. In this paper, a methodology is proposed for the generation of 3D thermal models using dual sensors, which involves the application of RGB and thermal images in parallel. Hence, the RGB images are used as the basis for the generation of the model geometry, and the thermal images are the source of the surface temperature information that is projected onto the model. Mining/industrial facilities representations that are obtained can be used for inspection activities.

***Keywords*—**Aerial thermography, data processing, drone, low-cost, point cloud.

I. Introduction

STRUCTURAL degradation occurs due to the confluence of temporal and operational factors, which affect the overall structural integrity of the system. As a consequence, structural inspection is a fundamental activity in order to guarantee the correct functioning and integrity of any type of infrastructure [1]. The traditional techniques based on visual inspection by a specialized technician are not suitable for analyzing large infrastructures, areas in poor conditions or difficult to access, all of which can lead to time-consuming, expensive and hazardous inspections [2]. Technological development and digitalization have allowed inspection through 3D models, which has led to an increased demand for this type of representation [3].

Nowadays, there is a wide variety of methodologies and equipment that allow the generation of three-dimensional models. Alternatives like classic topographic techniques, Laser-scanner, LIDAR techniques or photogrammetry can be mentioned. The Unmanned Aerial Vehicle (UAV) has been a great revolution in the capture of information, due to its economic advantages, flexibility and speed compared to other methodologies [4]. This type of platforms combined with photogrammetry have become the most used alternative, thus arising the term "UAV Photogrammetry" [5].

Recently, the miniaturization of sensors has allowed the use of different types of sensors in UAVs (RGB, thermal, spectral, multispectral, etc.). There is a wide variety of sensors available on the market. The use of low-cost sensors is the most widespread. The use of thermal sensors for the generation of 3D models is currently being studied in several areas. The application of thermal sensors is revolutionizing fields such as geological resources prospecting [6], building inspection [7], photovoltaic installations monitoring [8], archeology [9], etc. Numerous researchers have conducted studies on 3D thermal modeling [10]. Among the different possible strategies or approaches, some authors have proposed alternatives based on modeling with 2D thermal images [11], fusion of RGB and thermal images [12], [13] or mapping thermal images onto models [14] or point clouds [15]. Despite several proposals, no definitive results have been achieved, leaving a lack of a standardized methodology for representing temperature distribution along the surface [16].

This research aims to validate a methodological proposal for the generation of three-dimensional thermal models by dual sensors (RGB and Thermal) and UAV platforms. For this purpose, a proper large mining/industrial facility has been chosen to be modeled. Specifically, a cement plant has been selected. It is located in Mataporquera (Cantabria, Spain) and belongs to Cementos Portland Valderribas Group.

The facility has its own quarry for the extraction of limestone, which is crushed and mixed with other materials. The mixture is introduced into a furnace at high temperature where, after suffering a sintering process, is extracted as clinker. The clinker at high temperature is triturated and stored in the silo until it is required. As in all the cement facilities, the temperature control of the furnace, chimney and storage silo (three of its main structures) is fundamental. This is the reason why the chimney and furnace area are suitable case studies to be modeled.

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II. Instrumental Proposal and Methodology

A. Instrumental Proposal

The first UAV airborne thermal sensors applied were just modified handheld thermal devices [10]. The interest in this technology has allowed the rapid development of miniaturized low-cost sensors. The latest low-cost thermal sensors are dual sensors simultaneously integrate a non-metric RGB sensor and an Infrared or Thermal one [18]. The dual sensors allow the simultaneous capture of both sets of data, facilitating the interpretation and subsequent analysis of the captured thermal images.

UAV platforms can be mainly divided into two types: Fixed-wing and Multirotor [19]. The latter, also called multicopters, are the most used type for inspection activities, due to their ability to perform vertical takeoffs or landings, stationary flights, and their lower angle of rotation. For all these reasons, they are best suited to small areas, providing greater precision and detail. Fixed-wing aircrafts are more interesting for larger photogrammetric works, where their greater autonomy brings more benefits [20].

There is currently a wide variety of low-cost platforms and thermal sensors. The integrated equipment, with non-interchangeable sensor, are the most economical alternative.

In this work, the equipment selected to capture the images is a DJI Mayic Enterprise Dual quadcopter. It is a low-cost drone with integrated RGB and thermal sensors, developed for professional use. It is a widely versatile equipment for various activities, such as inspection, security, rescue, etc.

Fig. 1 DJI Mavic Enterprise Dual Drone

TABLE I
UAV Specifications

Weight	899 gr
Dimensions (deployed)	322x242x140 mm
Maximum speed	72 km/h
Autonomy	31 mins

The equipment incorporates a 12 Mpx M2ED RGB camera with a focal length of 4.5 mm, and an image resolution of 4056 x 3040 px, with JPEG storage format. The sensor also includes a FLIR Lepton® micro thermal camera, which captures JPEG thermal images simultaneously with the RGB data. The thermal sensor is an uncooled Vox Microbolometer, with a resolution of 640 x 480 px, and 8-14 microns spectral band.

B. Flight Plan

The capture of the image blocks is essential for the subsequent three-dimensional reconstruction process. The flight plan comprises a set of parameters (flight height, longitudinal and transversal overlap, flight speed, etc.), which are defined by the user, and allow the correct capture of the images.

In the case of flight plans, in order to capture thermal images, the recommendations vary with respect to the traditional guidance for RGB images. It is advisable to use lower flight heights in order to obtain a lower Ground Sample Distance (GSD) value, transverse and longitudinal overlap values of at least 80% in both cases, and flight speeds lower than 3 m/s. These recommendations are of special interest in the case of using low-cost non-metric sensors, where greater control of the process is required to achieve accurate results. These variations with respect to the traditional parameters are aimed at compensating the lower resolution, sharpness and contrast of the thermal images provided by this type of sensors.

Ultimately, the flight trajectory must be defined. In this aspect, two complementary flights are proposed. The first flight is nadiral, with a double grid geometry: the first set of passes is parallel, and the second one is perpendicular with respect to the previous one. This first flight over the installation was performed at an altitude of 120 meters (due to the 100-meter height of the chimney), with 80% frontlap, 80% sidelap and at a speed of 2.7 m/s

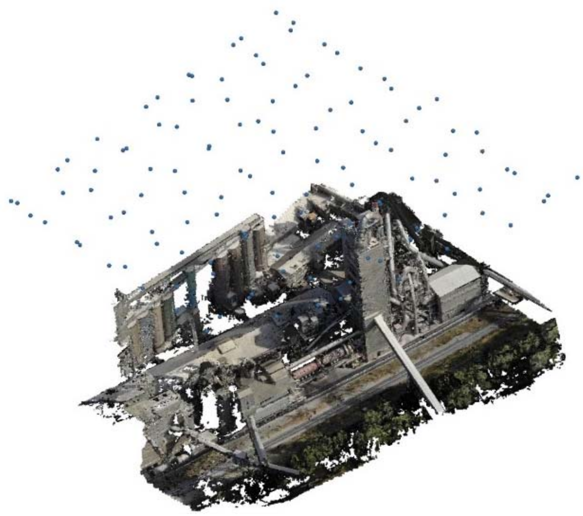

Fig. 2 Grid plan for the first flight

The second flight is a detailed one around the structure to capture oblique images that avoid the remaining occlusion zones, and increase the level of detail. The introduction of oblique images also improves the self-calibration algorithms that correct lens distortions during three-dimensional reconstruction. The detail flight comprised several strip trajectories, consisting of vertical passes at a distance of 40 meters from the structure.

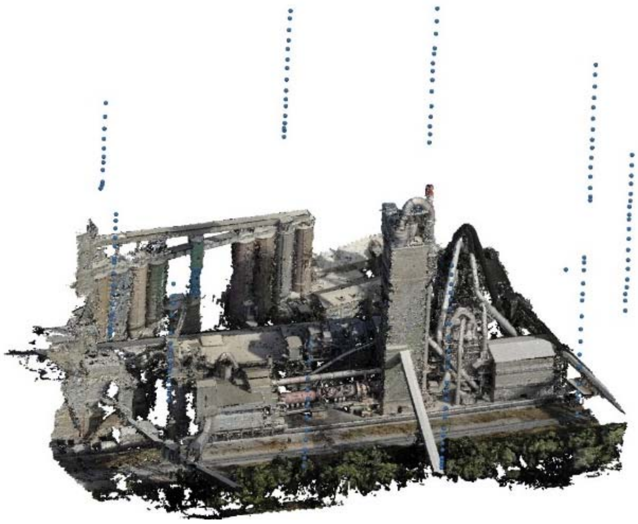

Fig. 3 Strip pattern path for the detailed flight

In UAV flight projects, weather is a fundamental factor that conditions the possibility of being able to fly and proper capture of the images. The time of capture is also of great importance for the capture of thermal images for inspection activities. It is recommended to carry out the flight early or late in the day, avoiding the incidence of solar radiation on the structure to be represented.

Complementary flight control must be performed by Ground Control Points (GCPs), which is one of the most influential parameters in the accuracy of the final model. When it comes to working with thermal images, square metal targets were used for their identification in the RGB and Thermal images. The GCPs array was placed following a regular distribution along the study area.

Fig. 4 GCP distribution over the facility

C. Photogrammetry Processing

Photogrammetric image processing is a widespread process, especially when it comes to RGB images. There is a wide variety of software on the market, such as Metashape, Pix4D, Photomodeler, DroneDeploy, etc., which implement Structure-from-Motion (SfM) techniques for an almost automatic reconstruction of 3D models from UAV. SfM techniques allow to obtain three-dimensional data and to represent 3D points from two-dimensional images.

Although each software implements its own workflow and algorithms, the overall SFM process consists of a similar set of simple steps. First, the software performs an image alignment, in which a spare cloud of tie points is generated by determining homologous points based on Scale Invariant Feature Transform (SIFT) algorithms. At the same time, the software determines the orientation parameters of the camera and its self-calibration. The orientation and the model are made according to a local reference system, so it must be georeferenced with GCPs, by means of their identification in the images. In the next phase, based on Multi-View-Stereo (MVS) and matching algorithms, a densification of the point cloud is performed on the basis of images acquired from different points of view. Once the point cloud is obtained, different by-products can be generated thanks to the software functions, such as TIN meshes, textures, Digital Elevation Models (DEM) or orthomosaics. However, processing thermal images often results in common problems, particularly during the orientation and correlation or matching stages, due to the lower resolution, contrast and sharpness of this type of images.

In the literature, it is possible to find different authors' approaches, which can be distinguished based on the modeling strategy employed [21]. However, no conclusive results have been provided by any of them [16]. These different approaches can be classified into three different categories: thermal 2D-image modeling, thermal image mapping into 3D models, and a combination or fusion of RGB and thermal images [5]. The proposed methodology belongs to the second category. This approach allows to solve the mentioned problems, while taking advantage of higher resolution sensors for the geometrical reconstruction by means of photogrammetry, thus guaranteeing a higher model accuracy.

The proposed methodology is based on the benefit of dual sensors, in which RGB and thermal images are acquired simultaneously, so that the telemetry data of the coordinates of the center of projection, yaw, pitch and roll of RGB images can be used for the orientation of thermal images.

The proposed methodology consists in the processing of RGB and thermal images in parallel. In this way, the thermal images are used to texturize the 3D model obtained from the RGB images. Firstly, the RGB images are processed according to the workflow implemented in the photogrammetric software, thus obtaining an estimation of the image orientation (telemetry data) and a point cloud. The telemetry data of each RGB image are implemented in its corresponding homologous thermal image, orienting the thermal images accurately. Then, the RGB point cloud is imported, and the thermal information from the infrared images is projected on it. Of all the available software, Agisoft Metashape software was used for image processing.

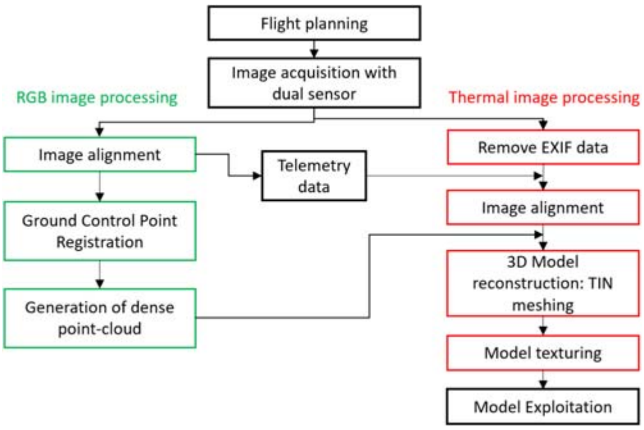

Fig. 5 Workflow for the proposed methodology

In the proposed case study, the images in JPEG format do not contain radiometric or thermal information of each pixel. Therefore, processing is implied. In case of using other sensors with different storage formats, it may be necessary to perform conversions of the information for temperature determination at each point of the model

III. Results

The results of the application of the proposed methodology are two geometrically analogous models. However, in the first one, each point of the cloud or triangle of the mesh contains color information obtained from the RGB images, and the second one comprises information related to the temperature of the surface that is represented.

Fig. 6 RGB 3D Point Cloud

Fig. 7 RGB 3D Shaded Model

Fig. 8 RGB 3D Model Textured

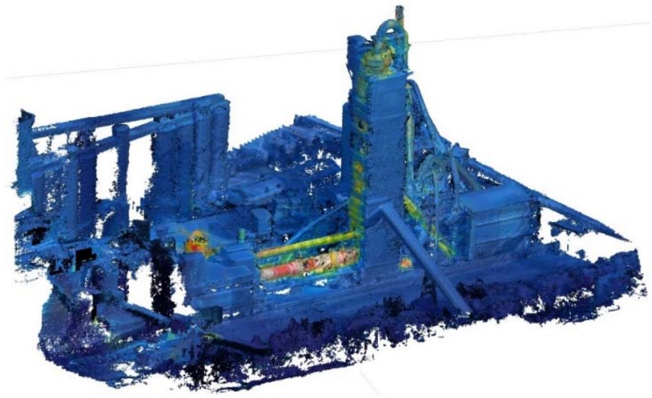

Fig. 9 Thermal 3D Point Cloud

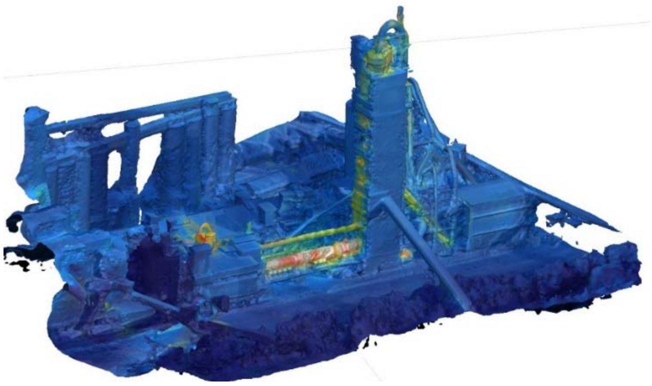

Fig. 10 Thermal 3D Shaded Model

The software used allows obtaining various photogrammetric by-products such as the point clouds, the wire mesh, the solid mesh or terrain triangulation, the texturized model, the shaded model and orthomosaic of the chimney. The latter are obtained with both thermal and RGB information, allowing more complete inspection activities.

IV. Discussion

Once the proposed methodology for the realization of 3D thermal models with low-cost dual sensors has been implemented, several interpretations can be made in view of the results:

- The proposal of two independent flights, a general one, with double grid, and a second detail flight, complicates the field work and increases the amount of time required. The combination of nadiral and oblique images not only provides a higher level of detail over the entire surface of the structure, but also increases the accuracy of the results by favoring the operation of self-calibration of the cameras that is carried out by the photogrammetric software during image processing.

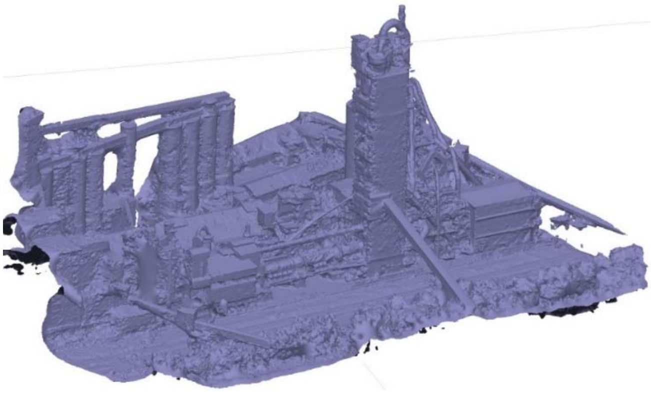

Fig. 11 3D Solid Model

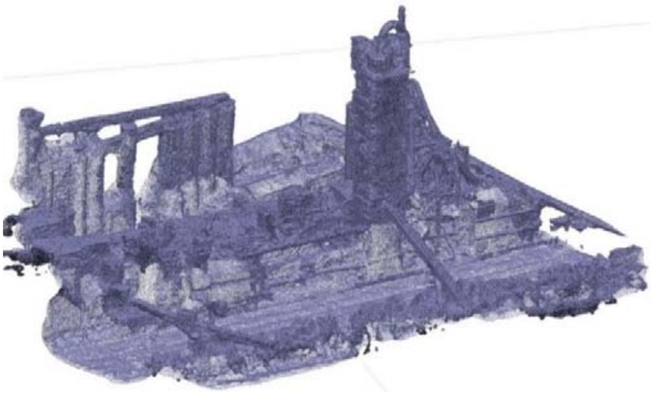

Fig. 12 3D Model Wireframe

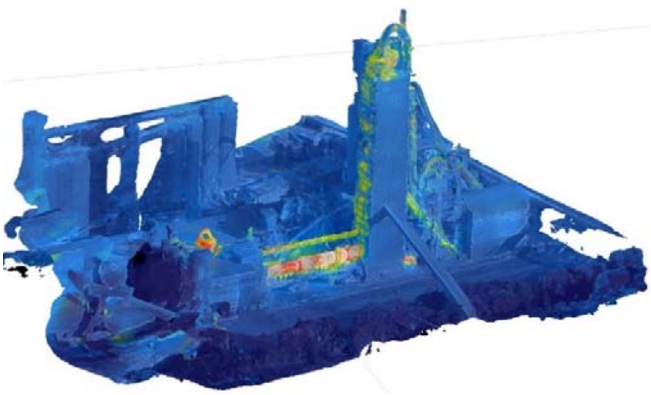

Fig. 13 Thermal 3D Model Textured

- The flight plan should be made according to the specifications of the sensor with the lowest resolution which, in the case of dual sensors, is the thermal one. In general, the infrared sensors of this type of equipment have more limiting characteristics than the RGB devices: lower resolution, smaller sensor size and focal length. Hence, the plan should be designed according to the specifications of this sensor, in order to ensure the GSD and overlay values recommended for this type of work.
- The proposed methodology is relatively simple, since it does not require major modifications with respect to the contrasted methodology applied for RGB images, or pretreatment of the images as proposed by other authors, e.g. [13]. However, it implies the need to use dual sensors, in which every captured thermal image has a homologous RGB image, which allows estimating the orientation of the photogrammetric block.
- The metric validation of the thermal model is contrasted, allowing the direct measurement of different magnitudes on it. Since it is based on a point cloud obtained from RGB images and a sensor with higher resolution, the accuracy of the model is of the order of the centimeter, as most models obtained with UAV and RGB sensors.
- The thermal validation of the model, on the other hand, is conditioned by the type of sensor and the storage format of the captured image. The sensor used in the present investigation allows the field measurement of temperatures, but not the storage of the temperature of each pixel in the image. Therefore, the model only represents the temperature differences on the surface of the structure in a qualitative way. However, there are sensors on the market capable of storing images in raw formats, which save the radiometric or temperature information for each pixel, allowing the measurement of surface temperature from the model.

According to these brief interpretations, the proposed methodology for the generation of thermal models allows to obtain accurate representations in a simple way, and with potential application in the field of structural inspections.

V. Conclusions

In view of the models obtained and their interpretation, it can be concluded that the proposed methodology allows achieving the objective sought. The generation of 3D models as point clouds or meshes, with quantitative or qualitative thermal information, can be done by projecting thermal images on models obtained with RGB images. The proposed methodology shows to be a tool with great potential in the field of inspections of mining/industrial facilities.

Thermal models depend on the sensor to be able to represent quantitative or qualitative values of the temperature. However, in both cases they allow the identification of anomalies associated with the surface temperature difference. In addition, due to the centrimetric geometric accuracy of the model, it allows the measurement of lengths, areas or volumes to quantify the magnitude of the anomaly.

In conclusion, UAVs with low-cost dual sensors are an alternative with great potential for the generation of 3D thermal models, using RGB images for model generation, and thermal images to project thermal information. These representations allow the identification of thermal anomalies, which is necessary for diagnostics in the field of structural inspections.

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