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Earth observation advancements in a changing world

Edited by Chirici G. and Gianinetto M.

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THERMOGRAPHIC CHARACTERIZATION OF A LANDFILL TROUGH AN UNMANNED AERIAL VEHICLE

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ABSTRACT:

The use of the thermal imaging camera for Unmanned Aerial Vehicle (UAV) survey is to date very common for environmental analysis, especially if high spatial resolution images are required. Some analyses require images to be acquired close to sunrise, to avoid the influence of the incident solar radiation on the surface temperature, as in the case of a landfill survey. Indeed, thermal anomalies due to generated landfill biogas can be characterized once other heat sources are excluded. In this framework, thermal images need to be processed similarly to optical images by typical photogrammetric workflows producing both a Digital Surface Model (DSM) and an ortho-image. The low spatial resolution of thermal cameras, optical distortion and low and homogeneous spatial distribution of radiant exitance at sunrise require, however, an adapted workflow. In this work, some first tests were carried out at a landfill in Palermo (Italy) to evaluate the feasibility of using thermal images to determine the DSM and the thermal ortho-image of the area, aiming to identify thermal anomalies related to landfill heat sources such as biogases.

1. INTRODUCTION

Unmanned Aerial Vehicles (UAVs) have been used for many applications in recent years in the field of cultural heritage, archaeology, 3D mapping and environmental monitoring. In particular, the UAVs have been used to 3D survey and modelling of a historical building (Carnevali *et al.*, 2018; Lo Brutto *et al.*, 2018) and archaeological sites (Lo Brutto *et al.* 2014; Erenoglu *et al.*, 2017). Also in a hazardous situation, the 3D documentation was done with UAVs (Zaragoza *et al.*, 2017). Some works have been carried out for 3D mapping in civil engineering applications (Siebert and Teizer, 2014; Santos de Melo *et al.*, 2018) or for environmental monitoring (Manfreda *et al.*, 2018) and natural hazards monitoring (Gomez and Purdie, 2016).

One of the most recent applications of UAVs is the inspection and monitoring of landfills. For example, some applications were carried out to monitor slow-evolving processes such as waste compactness and landfill subsidence; these processes are recognised as threats in causing the major economic loss to management of rubbish damps (Gasparini *et al.*, 2014).

Some UAVs aerial surveys for landfill monitoring have been conducted using thermal sensors. In Baiocchi *et al.* (2018) first tests have been performed to evaluate the altimetric and thermal accuracy of a UAV landfill survey.

Other recent works have been aimed at measuring gas emissions through thermal imaging cameras pointing out that emissions are localized in hotspots points (Röwer *et al.*, 2011; Xu *et al.*, 2014) due to the mixed nature of the landfills (composed by litters, soil, organic matter, leachate liquid, etc.).

An optimum landfill management requires the detection of landfill gas (LFG) emission hotspots. Thus, thermal images are clearly useful as the gas emissions generally are observable as thermal anomalies. Indeed, the degradation of organic waste produces LFG mainly composed of methane (CH_4) and carbon dioxide (CO_2). The former is generated by an exothermic process which warms up the surrounding area (as these gasses are characterized by temperatures up to 60° C). The detection of thermal anomalies due to generated LFG could be performed once other heat sources are excluded; thus, leading to the need of performing acquisitions close to sunrise, to avoid the warming up of the surface due to the incident solar radiation... Some limitations in the use of the thermal sensors to detect LFG emission hotspots have been highlighted in Lewis *et al.* (2003); these limitations include sunlight, ambient temperatures, wind, surface materials and distance between a sensor and the source. These authors conclude “that unless all the fundamental factors are clearly understood and addressed, the technique (*i.e.*, infrared thermography) currently can only be used as a screening tool rather than as a precise tool to detect landfill gas leakages”.

Ground-based surface campaigns for locating emission hotspots are generally difficult as time-consuming and labour-intensive. In addition, landfills are often moderately/largely extended (up to hectares in area) and not always easily accessible. For these reasons, the UAV survey appears to be worthwhile to detect hotspots’ emissions.

An aerial infrared thermography approach to identify thermal anomalies with a good resolution over a large region of the landfill surface was showed in Tanda *et al.* (2017). A simplified procedure to evaluate the biogas flow rate emerging from the soil into the atmosphere, based on infrared thermography measurements, was also presented in this paper.

Fjelsted *et al.* (2018) have used an UAV-mounted thermal infrared camera’s to delineate landfill gas emission hotspots; the authors have evaluated the methodology in two landfills test areas of 100 m^2. The relationship between landfill gas emissions and soil surface temperatures were investigated in these case studies through several measuring campaigns, in order to cover different atmospheric conditions. Because the extension of the area of the landfills and the high spatial resolution often required for these type of survey, it could be useful to process thermal images similarly to optical images. Thermal images, acquired from UAV, can be processed by applying the typical

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photogrammetric workflow, and in particular, the photogrammetric/structure-from-motion (SfM) approach, prior to use these data to localize gas emission hotspots.

The use of thermal images in a typical photogrammetric/SfM approach is showed in Mauriello and Froehlich (2014) and in Westfeld *et al.* (2015). These authors have investigated the possibility to efficiently use SfM approach with thermal images for 3D point cloud generation; these works are, however, aimed at buildings survey. In environmental survey, the use of photogrammetric/SfM workflow allows obtaining from thermal data the DSM beyond the thermal ortho-image of the area. However, low spatial resolution of thermal cameras, optical distortion and low and homogeneous radiant exitance spatial distribution impose an adapted workflow.

Within this work, preliminary tests were carried out to evaluate the feasibility to use thermal images acquired from a UAV for DSM extraction and for ortho-image production in a landfill environment. The study area is within the landfill of Bellolampo (close to Palermo, Italy) where landfill managers are interested in thermal behaviour and actual DSM that undergo temporary storage, consolidation, compaction and transfer of waste material. The work was carried out in a quite small area test (about 2.5 hectares) of the landfill. In this operative scenario, we performed optical and thermal flights to compare outcome from the thermal images process with a medium/large UAV (~7 kg weight).

2. STUDY AREA

The "Bellolampo landfill" is used as landfill for the waste of the city of Palermo (Sicily, Italy) and for some municipalities near Palermo. The landfill receives the waste of about one million people; on average about one thousand tonnes of waste per day is stored in the landfill. The "Bellolampo landfill" is located 5 km from the city, in the North-West of Palermo, in a site far away devoted as the landfill of the city (Figure 1). The nearest inhabited settlement is far away just 1 km south of the landfill facilities.

The landfill covers on the whole an area of about 30 hectares and is located at an altitude of about 500 m above sea level (a.s.l.), between Badami Plain and mount Gibilforni (Figure 2).

Figure 1. Positioning of "Bellolampo landfill" (from Google Maps©).

Figure 2. The "Bellolampo" site (from Google Maps©).

In addition to a historical "reclaimed" landfill in which waste was accumulated without controls for almost 3 decades, five more landfills have been built in the last 2-3 decades. More recently, five controlled landfills were built starting from 1990 to 2010; these latter nowadays are closed. A sixth landfill (namely the landfill #6) is under construction since 2015, and it is currently in operation. This latter landfill has an area of about 90,000 m^2 and a volume of about 1,700,000 m^3; it is composed by four sectors (namely sector #1 to sector #4, numbered counter-clockwise from the southeast corner of the landfill #6). Altitudes of the first two sectors range approximately between 510 and 520 m a.s.l., while altitudes of the last two sectors extend up to ≈ 560 m a.s.l.. The first two sectors are already filled and covered by a capping. High-density polyethylene (HDPE) has been used as cap (Figure 3).

Figure 3. HDPE used as cap for the sector #1 and sector #2 of the landfill #6 (from RAP S.p.A. website).

This geomembrane cap contains landfill gas and prevents precipitation becoming leachate, and a floating cover prevents odour emissions. Biogas recovery facility as well as leachate storage and treatment plants are present. The Landfill gas plant is characterized by an installed power of 6.35 MW generated at municipal solid waste (MSW).

The study was limited to only part of the landfill #6; the area of interest is about 130 m x 200 m and is delimited by a red line in figure 4. The area is almost all covered by an impermeable cap; only a small part is partially vegetated and covered with soil.

Figure 4. Flown area (red box) over an image from Google Maps©.

3. DATA ACQUISITION

The area of interest was flown on the 30th of January 2018 by an NT-8 Contras octocopter carrying on-board an Optris PI450 thermal camera and a GoPro HERO Black 4 camera (Figure 5). The Optris PI450 is a microbolometer acquiring in the 7.5 - 13 µm spectral range with 40 mK thermal sensitivity; it produces thermal images with a resolution of 382 pixels x 288 pixels. GoPro HERO Black 4 is a well-known action camera that could be used for photogrammetric image acquisition in contexts where is not required a high level of accuracy (Hastedt *et al.*, 2016).

Figure 5. The NT-8 Contras octocopter used for images acquisition.

Four strips were planned at an average UAV flight height of 50 m above the ground level; the flight direction was parallel to the contour lines (Figure 6). The acquisition was done by two flights; the first acquisition was carried out at 06:20 local time, very close to sunrise (starting at 06:10 local time) under diffuse solar radiation and the second just after sunrise with direct plus diffuse solar radiation (at 07:00 local time).

With thermal camera and GoPro, only videos have been acquired for the area of interest. The resulting thermal images were characterized by a pixel spatial resolution of ≈ 14 cm; about 5 times coarser than the visible images (≈ 3 cm).

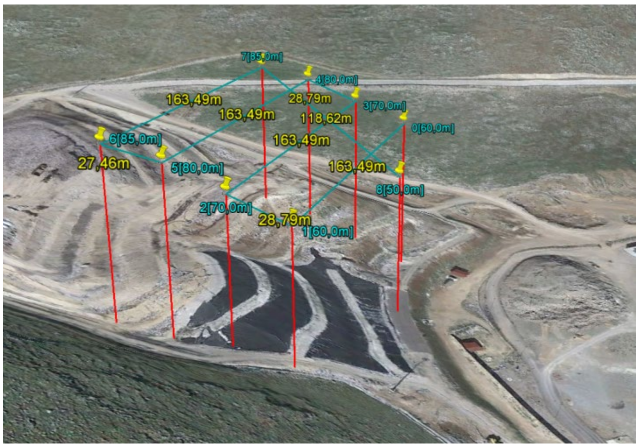

Figure 6. View of UAV acquisition scheme.

Aluminium targets (20 cm x 20 cm) were deployed on the ground as suitable ground control points (GCPs) for thermal images. Aluminium is indeed characterized by very low emissivity (ε=0.04-0.07 for foil and rough surfaces, respectively) resulting in pixels with very low brightness temperature. Even though the night-time thermography was characterized by low homogeneous radiative temperature these targets were clearly detectable within the scene. On the other hand, these aluminium targets were not simply detectable on the visible images due to sparse vegetation mixed to waste emerging from the soil. The coordinates of the targets were measured by a Network Real Time Kinematic (NRTK) survey using a Topcon Hiper V receiver (both GPS and Glonass) (Figure 7). NRTK positioning was carried out using the hardware and software infrastructure of the permanent Netgeo-Topcon network (http://www.netgeo.it/index.php) framed in the reference system ETRF2000 (powered by IGMI, the Italian Military Geographic Institute) and in particular via the VRS (Virtual Reference Station) stream. The survey has a planimetric and altimetric accuracy of the centimetre level.

Figure 7. GNSS survey of the aluminium targets.

4. DATA PROCESSING

The first step in data processing was to extract the single frames from the video sequences. One frame per second was extracted from the videos of both the thermal camera and the GoPro. As the ground-speed of the UAV was 2 m s^{-1} a sequence of images with a high percentage of coverage was obtained from both flights.

Visible and thermal images were processed using the Agisoft PhotoScan Pro software; the typical photogrammetric/SfM approach was carried out by image alignment and estimation of internal camera parameters, dense point cloud computing, DSM and ortho-image production.

To use thermal images with Agisoft PhotoScan Pro software it was necessary to convert the thermal sequence in TIF images and to reduce the image radiometric resolution to 8 bit.

Three different Agisoft PhotoScan Pro projects have been setup: two with the thermal images of the first and second flight and one with the visible images of the second flight. In this way, it was possible to obtain three DSMs and three ortho-images (two from thermal images and one from visible images) of the test area (Figure 8).

Figure 8. Ortho-image from GoPro data.

5. DATA ANALYSIS

Thermal images are suitable to detect some landfill characteristics not clearly visible elsewhere. Pipelines used for biogas conduction (Figure 9, upper panel) generally show temperatures (Figure 9, lower panel) higher than the surrounding ground, with some pipelines showing values much higher than others. Some temperature features are also clear in landfill zones with and without capping (in this latter case often close to boundaries).

The acquisition at sunrise allows neglecting the ground heat flux due to its inversion at the surface. During the first flight, features due to underground heat sources are clearly visible; although under diffuse solar radiation (Figure 10, left panel) brightness temperature was quite low. During the second flight underground heat source were masked by direct shortwave radiation warming up surface micro-reliefs (Figure 10, right panel) and activating also the vegetation covering the soil (as part of the landfill is not covered with capping). The brightness increase between the two acquisitions was 4.8 °C on the average, with a 2.1 °C standard deviation. Minimum and maximum percentiles, 1 and 99% were P_{01} = 2.8 °C and P_{99} = 6.9 °C, respectively.

A high spatial resolution DSMs characterizing the landfill at the time of the acquisition was obtained by processing both thermal and visible images (Figure 11). These products are useful as active landfills are characterized by morphologies quickly evolving in time due to waste movement and compaction.

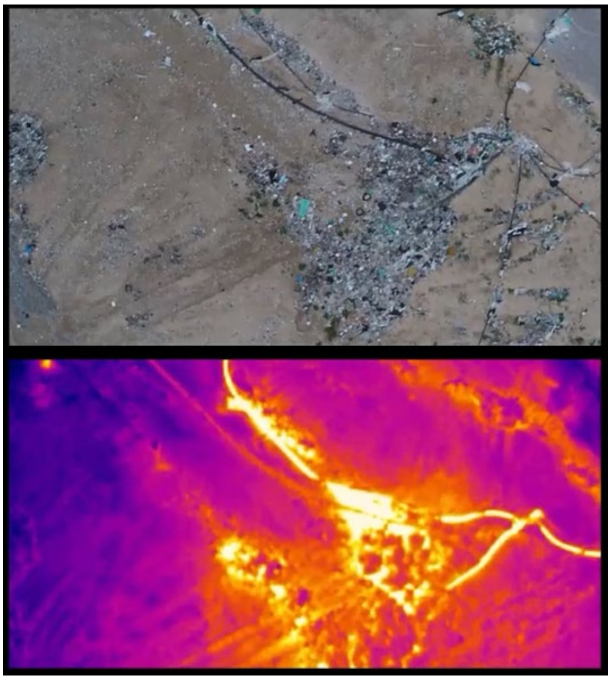

Figure 9. A detail of the landfill including biogas pipelines (upper panel, visible image) and brightness temperature of the same area (lower panel, thermal image).

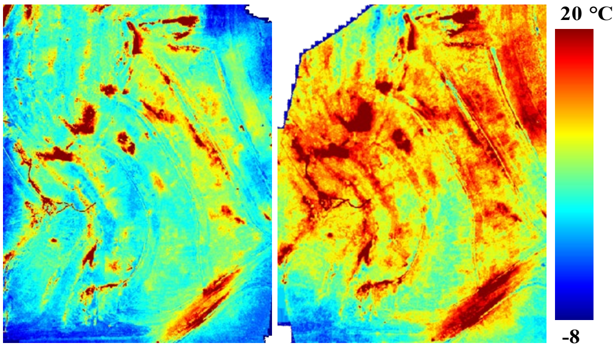

Figure 10. Brightness acquired at 6:20 local time with diffuse radiation (left panel) and at 7:00 under diffuse plus direct radiation (right panel).

DMS obtained by thermal images, DSM_{TIR}, acquired during the first flight was compared to the more standard product from optical image, DSM_{VIS}, to test the reliability of the former one. Altitude values are strongly correlated ($r^2 \approx 0.98$) with no notable over- or under-estimation (the slope was 0.999) and quite low dispersion (MAE ≈ 1.1 m) (Figure 12). Lines characterizing DSM_{TIR} 10° and 90° percentiles are also reported (P_{10} and P_{90}, respectively) to confirm that few pixels fall outside of these extremes. The colour scale (blue to yellow to red) is proportional to the density of pixels falling within the scatterplot bin element. The colour scale highlights that most of the pixels (in red) are aligned on the 1:1 line (part of the study area covered by ground control points); while a second cluster of pixels is observed over the part of the landfill were no or few aluminium targets were deployed.

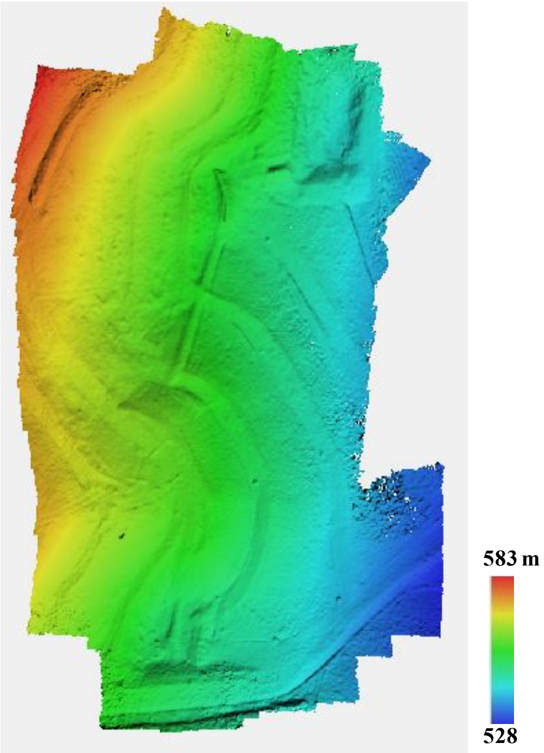

Figure 11. *DSM*VIS derived from the acquisition under direct plus diffuse solar radiation.

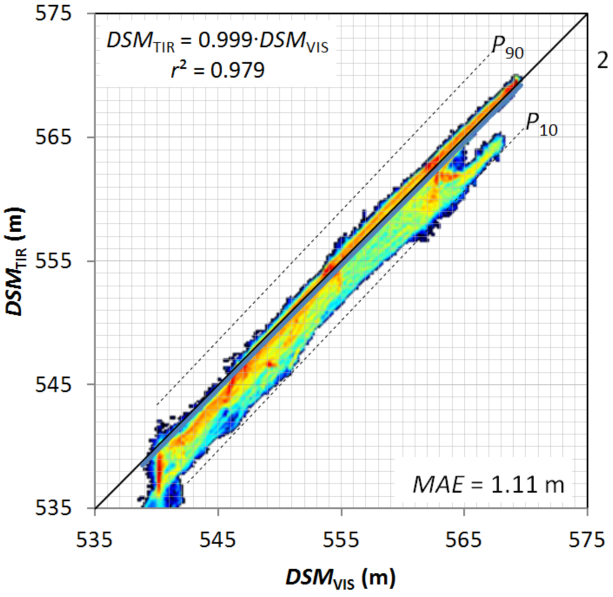

Figure 12. *DSM*VIS from an overpass under direct plus diffuse solar radiation *versus DSM*TIR from an overpass just after sunrise under diffuse solar radiation.

6. CONCLUSIONS

The work has shown the results of some first tests carried out for the thermographic characterization of a landfill in Palermo (Italy). The thermal images were acquired by a UAV and were used to identify thermal anomalies related to landfill heat sources.

Thermal images acquired close to sunrise, with only diffuse and no direct solar radiation, allow highlights features due to underground heat sources such biogas production, emission or storage; while daily ground heat flux due to net radiation can be neglected due to its daily inversion at the surface. If a thermal image is acquired during daytime or even when direct shortwave radiation hit the surface, underground heat source would be masked by warmed up surface micro-reliefs and by evaporation and transpiration processes of soil and vegetation if occurring. A DSM derived by processing the thermal images has been proved to be an unconventional alternative to that obtainable from visible images although further and more in-depth tests must be done to verify the metric reliability of the DSM produced from thermal images. Furthermore, the processing step highlighted that aluminium targets turn out to be suitable ground control points for DSM and ortho-image production from thermal images; even when, close to sunrise, exitance and reflectance are quite low and standard visible targets cannot be easily detected in thermal and visible images.

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