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# 3D tools for building and infrastructures inspection from thermal UAS data: first steps

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## Abstract

Thermal imaging has been widely used for the inspection of human-made and natural scenarios, from electrical installations and advanced machinery to buildings. Regarding buildings, it can be used to assess problems concerning heat, airflows, and water. Hence, thermography has been increasingly applied to the energy efficiency of new and old buildings. Some examples of applications are the detection of heating and cooling losses, moisture sources, missing insulation, floor heating failures, and the evaluation of building restorations. However, the main drawback of thermal imagery is its reduced resolution, e.g., 640x512, which is significantly lower than RGB imagery. In the case of buildings, cameras or thermal sensors mounted on UAS (Unmanned Aerial System) offer a wider range of possibilities by acquiring areas not accessible by other surveying methods. This paper presents a tool that allows building dense 3D thermal point clouds applied to conserving buildings and infrastructures inspection. Also, the aim of this work is to provide a visualization solution of the generated point clouds, thus allowing a human operator to analyze building defects. Accordingly, the rendering is improved by taking advantage of modern Graphical Processing Unit (GPU) capabilities, while also considering the occlusion for the accurate assignment of thermal information to the point cloud. Due to the high response time of the procedure, the complete pipeline is accelerated using GPU programming. Finally, our method is proven to generate point clouds with a higher number of points and density than notable commercial solutions, while also lowering the response time.

*Keywords:* Building, Infrastructures, Thermal, Drones, Insulation Failures

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## 1. Introduction

Thermography or Infrared (IR) thermal imaging constitutes one of the main data sources in the Remote Sensing field to survey human-made and natural environments. Thermal sensors acquire the reflectance emitted by surfaces and translate it into temperature. In contrast to visible imaging devices (RGB, Red-Green-Blue), thermographic sensors do not need external light sources for acquiring information, thus making them more reliable for applications such as night vision. Also, information captured in a different spectral interval offers a different range of applications with respect to RGB, from the detection of fire, plant disease, or gas leaks to surveillance. Regarding buildings, thermography is better suited for locating structural failures, e.g., related to insulation, failures in the conservation of heat, and water leakages (Vollmer and Möllmann, 2017). Furthermore, these failures can be detected by visually inspecting thermal data. To this end, this work proposes a framework for reconstructing dense 3D thermal point clouds, aimed at providing a visualization tool for the detection of building failures.

Thermal data can be either collected using manual devices or automatized processes, such as aerial and terrestrial surveys by means of drones (Unmanned Aerial Vehicles, UAVs) and robotic platforms. In contrast to the manual collection, the use of platforms outputs a large volume of data that needs to be later analyzed. Therefore, building an appropriate 3D reconstruction easies the inspection of the target scenario. Among 3D models, point clouds are significantly more reconstructed in previous work using UAV imagery, as triangle meshes are generated using incomplete and noisy point clouds, thus leading to inaccurate results. The reconstruction of thermal point clouds is straightforwardly achieved using photogrammetric techniques, such as Structure from Motion (SfM). However, it is frequent to find badly estimated scenarios with wrong or no geometry. This occurs as a consequence of reflectance depicted in thermal imagery, which is shown smoothed out due to reflectance transmittance and inaccuracy of thermal detectors (Sledz et al., 2018). Hence, finding common features between sequences of thermal images is challenging. On the other hand, the estimation of RGB point clouds seldom presents the cited failures, and therefore, can be used as the baseline for building 3D thermal point clouds. Also, the number of found features is significantly bigger than the density of the resulting point cloud.

Besides providing a point cloud, other concerns are based on the visualization, the accurate assignment of thermal information to geometry, and response time. First, point clouds may be sparse and noisy, so previous work has led to homogeneous rendering of large point clouds using modern Graphical Processing Unit (GPU) capabilities through the OpenGL (Open Graphics Library) framework (Schütz et al., 2022). Then, the accurate assignment of thermal data to points is performed by firstly considering occlusion from camera viewpoints, thus avoiding linking foreground data to background points (Jeong et al., 2021). Occlusion has been barely addressed in the literature for imagery projection. Also, previous work performs the time-consuming processing in the CPU, without augmenting the imagery resolution, thus discarding most of the starting points. Then, values can be aggregated in 3D points using penalty functions to reduce the distance between the aggregation result and gathered values. This approach has been mainly applied to image compression and other Computer Science fields, such as decision-making applications (Paternain et al., 2015). Finally, the whole pipeline, from projection to occlusion detection, is implemented in the GPU using parallel programming. Few studies have previously addressed the acceleration of 3D reconstructions besides the classical SfM algorithms. As a result, our work shows that point clouds of nearly 100M points are built in a few minutes, while other approaches, including commercial solutions, produce results of lower quality with higher response time (López et al., 2021).

Regarding the inspection of human-made buildings, previous work has assessed the reconstruction of thermal point clouds for buildings with the aim of inspecting cracks and façade openings. Photogrammetric techniques have been used to reconstruct both visible and thermal points clouds, thus allowing to co-register them (Jarząbek-Rychard et al., 2020). Additionally, the fused point cloud is classified to discern materials using geometric, color and thermal properties, in order to evaluate façade openings in wall-labeled points. Similarly to the previous work, the registration of point clouds can be used as a first step, i.e., a coarse registration (Lin et al., 2019). Following this step, RGB and thermal images are matched with radiance-invariant feature transform (RIFT) to provide congruency in images with different intensities. Mismatches are then discarded according to the spatial information supplied by the GPS/GNSS (Global Positioning System; Global Navigation Satellite System). As a result, the camera pose of every thermal image is estimated from 2D and 3D matched features, thereby allowing to project thermal data into a dense RGB point cloud.

Wall cracks have been further investigated in 2D. Instead of focusing on the detection of building defects, they are aimed at determining the most appropriate acquisition conditions to facilitate the detection of wall cracks (Bauer et al., 2016b, 2016a). Given the challenges of reconstructing buildings, several methods have been compared at once to evaluate the obtained errors. The feature detection phase is mainly hardened by surfaces without features (flat surfaces) or repetitive patterns (symmetric objects, e.g., windows). Hence, the reconstruction was addressed by 1) co-registering point clouds, as previously described, 2) co-registering images, 3) fusing an RGB point cloud and thermographic 2D line segments, 4) fusing an RGB point clouds and thermographic 2D features, and 5) co-registering 2D line segments (Hoegner et al., 2016). As a result, it was shown that 3D space-based methods were more accurate, rather than working in 2D since most of the images could not be matched. However, there exist algorithms capable of dealing with images of different intensities, e.g., RIFT or ECC (Enhanced Correlation Coefficient). With this algorithm, methodologies based on image fusion and subsequent projections into a dense RGB point cloud are shown to be more accurate (Javadnejad et al., 2020; López et al., 2021).

Besides wall fractures, 2D thermography has been applied to detect hidden structures of old human-made buildings through their different heat flow, the inspection of private heating systems, detection of non-insulated materials, detection of building defects that lead to air gaps or the identification of water leaks in buildings due to moisture (Vollmer and Möllmann, 2017).

## 2. Materials

The acquisition of thermal imagery can be acquired through a wide range of cameras (Gade and Moeslund, 2014). More recently, the use of UAV-based sensors provides high-resolution images from dual payloads by collecting thermal and panchromatic captures. In our study, we used DJI Zenmuse XT2 on DJI Matrice 210 RTK as shown in Figure **1**. Moreover, a multispectral camera was mounted on the drone for the characterization of surveyed materials, but this topic is out of the scope of this work.

**Figure 1**. Unmanned aerial vehicle (DJI Matrice 210 RTK) and a thermal camera (DJI Zenmuse XT2).

Regarding sensor radiometric calibration, metadata parameters are precalibrated by the manufacturer, while a few values can be configured through in-situ measurements to improve temperature estimations. Hence, the environmental temperature is measured and set as the background temperature to replace the default value. Flat Field Correction (FCC) is also performed before the flight to enhance image quality. According to the quality of RGB images, they have a resolution of 4000x3000. On the other hand, the thermal imagery has a resolution of 640x512. Considering the spatial resolution of both image types, the application of the algorithm proposed by Alfonso et al. (López et al., 2021) allows us to generate point clouds with a GSD (Ground Sampling Distance) close to 1 cm. This level of detail is mandatory for multiple applications ranging from building inspection to the monitoring of solar plantations where the level of detail plays an important role.

## 3. Results

In this section, we present the results from applying the algorithm for the generation of thermal point clouds. We are going to briefly expose their main advantages to be used in the monitoring of solar panels.

### 3.1. Study area

The dataset was collected from the UAV flight at the solar plantation of the University of Jaén, Spain, and Solar Jiennese S.L, located in Jaén, as shown in Figure **2**. The solar panels are mounted over the roof of the car park and the surveyed area is around 1.5 ha. Regarding the dataset, 400 thermal and RGB images were simultaneously captured at 50 meters of altitude. The flight time was 25 minutes approximately.

**Figure 2**. The surveyed solar plantations, which is located at the University of Jaén.

### 3.2. Thermal point clouds

In this section, we present the proposed methodology for generating dense thermal point clouds aimed at easing their visualization.

First, a dense RGB point cloud is reconstructed using Structure-from-Motion (SfM), from which external and internal camera parameters are obtained. Therefore, the camera matrix for every viewpoint is known. As a result, 3D points from the RGB point cloud can be unprojected to the original images. Similarly to this procedure, thermal point clouds can be generated with photogrammetric techniques, although they present several drawbacks according to the core behaviour of SfM. Features are not easily distinguished among several thermal images, thus hardening the estimation of viewpoint parameters, as shown from the point cloud gaps in Figure 4. Besides that, the Ground Positioning System (GPS) inaccuracy leads to areas with non-uniform elevation.

Alternatively, the RGB point cloud is proposed to be the reference. Instead of generating two individual point clouds, thermographic and visible data collected from UAVs are co-registered. Due to intensity differences in them, the algorithm to match both types of images must be resilient to the variance of radiance. In contrast to the frequently used SURF (Speeded-Up Robust Features) and SIFT (Scale-invariant feature transform) algorithms, the Enhanced Correlation Coefficient (ECC) is able to work under these conditions.  To this end, it is parameterized by the aimed precision as well as the number of maximum iterations whether convergence is not achieved.

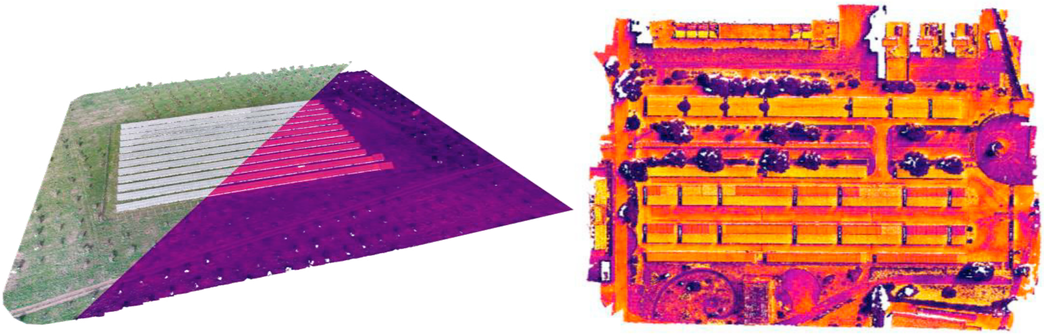

**Figure 3**. Point clouds of the studied areas. The left image shows a mixed visual representation of RGB and the thermal point cloud of the Solar Jiennense's plantation.  The right image is the resulting thermal point cloud of the solar plantation at the University of Jaén.

Once images are matched, 3D RGB points can be unprojected to 2D (RGB image space), and subsequently projected to the thermal space, correlated by a homography matrix extracted from the ECC algorithm. During this process, occlusion must be considered to avoid assigning thermographic information from foreground surfaces to background objects. To this end, a depth-buffer or z-buffer is built for every viewpoint. Accordingly, the index of the nearest point for each pixel is obtained. Then, points observed as the nearest are projected to the thermal space to augment their information.

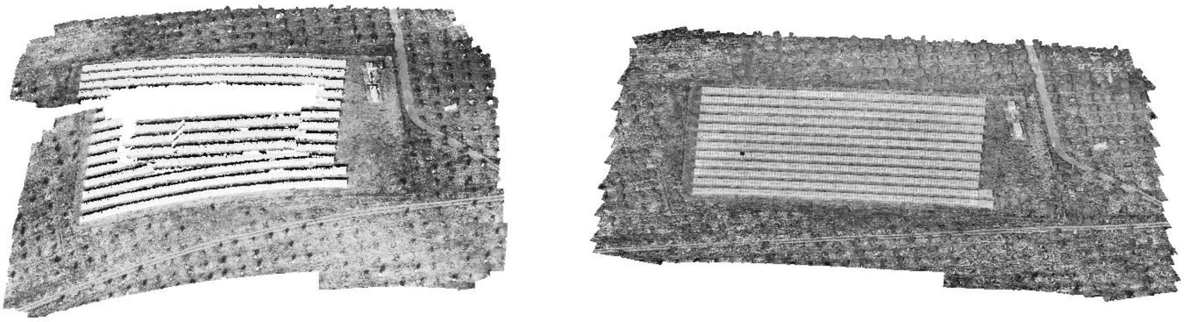

**Figure 4**. Comparison of thermal point cloud generated by Pix4Dmapper (left) and ours (right).

As this work is aimed to provide a visualization tool for human operators, the last step is to improve the visualization of point clouds, as shown in Figure 5. Despite their high density, their discrete rendering is frequently noisy due to gaps. Instead, OpenGL's modern tools in the Graphics Processing Unit (GPU) are applied to the rendering by averaging neighbourhood information, thus showing a uniform appearance and easing the assessment of infrastructures. Furthermore, the whole pipeline is implemented in the GPU instead of using the classical one, thereby avoiding stages that are not useful during the visualization of point clouds.

**Figure 5.** Noisy image from OpenGL's naive rendering in compute shaders and improved rendering by aggregating the neighbourhood information.

## 4. Conclusions

This paper presents a tool that allows enhancing 3D point clouds with thermal information. The theoretical foundations of the method are described in our previous work (López et al., 2021). This process has already been implemented in a tool (GEU-Thermal) that offers inspection services with this technology. Apart from the generation of 3D thermal data, the algorithm is accelerated on GPU by achieving a more efficient overall response time for fusing thermal imagery on dense point clouds. The aim of this study is to demonstrate the utility of our techniques for a wide range of applications application concerning the conservation of buildings and infrastructures. In future work, we will focus on advances in (1) the identification and segmentation of building materials, and (2) the comparison of thermal point clouds produced over time will allow us to study multi-temporal data.

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