Hyperspectral TIR sensor for building heat-loss detection

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ABSTRACT - *This work, carried out in the framework of Rubí-Brilla project, aims at detecting heat loss over industrial building covers in Rubí* (*Catalonia, Spain*) *using TASI-600 night acquisitions. The comparison of two hyperspectral TIR datasets acquired with a 6-hour time span led to the generation of a temperature gradient map and the detection of temperature change patterns related to heat-loss fluxes. A first study on the relationship between thermal behaviour and cover types was also carried out using the hyperspectral emissivity information. Different materials within the same roof were first discriminated by applying the Principal Component Analysis (PCA) technique to the emissivity profiles, and then characterized using the 32-band emissivity data.*

1 INTRODUCTION

Energy-efficiency is the first step toward achieving sustainability in buildings and infrastructures. Energy-efficiency helps control rising energy costs, reduce environmental footprints and increase the value and competitiveness. This issue, already important when dealing with private homes, becomes crucial for industrial facilities: a better management of the energy involved in the production activity leads to saving fixed production costs and, eventually, to a more competitive positioning in the market. Besides, buildings heat-loss and inefficient use of indoor heat cause a great waste of energy, with ultimate consequences on people's livelihood in terms of quality of the indoor thermal environment.

The Thermal Airborne Spectrographic Imager 600 (TASI-600) is a hyperspectral infrared sensor manufactured by the Canadian company ITRES©, which started being operated by the Institut Cartogràfic i Geològic de Catalunya (ICGC) at the end of 2009 [Pipia, 2010]. The system works in a pushbroom configuration and provides the user with 32-band hyperspectral data in the 8-11.5µm spectral range. The nominal Field-Of-View (FOV) is approximately 40°, and it spreads over 600 spatial pixels. The TASI gives the opportunity to measure and retrieve information concerning skin-temperature and emissivity spectrum of the imaged scene. When flown over man-made areas, such as an industrial district, TASI-based absolute temperature becomes a reliable descriptor of heat leaks through roof covers, whereas patterns detected within hyperspectral emissivity images usually account for different properties of the cover material.

Following this approach, TASI data were acquired over an industrial area in Rubí, the second largest industrial district in Catalonia (Spain), in the framework of the project Rubí Brilla [Rubí,2013]. In this paper, the measurement campaign carried out by ICGC in the framework of the project Rubí Brilla is described. The temperature maps corresponding to each flight are compared in a pixel-by-pixel approach in order to detect changes in the temperature patterns, which

Figure 1 - TASI flight plan over Rubí

TASI field of view (FOV)	40°
Flight height	1600
# of Spectral Bands	32
# of Spatial Pixels	600
Along-track Pixel's size	2 m
Along-track Pixel's size	2 m
Swath	1100 m

Table 1 - Flight and sensor main parameters.

can be related to heat-loss fluxes. Similar thermal dynamics are looked for and compared to hyperspectral emissivity information. Finally, principal Component Analysis (PCA) is applied to stress the existence of possible relationships between thermal behaviours and cover materials.

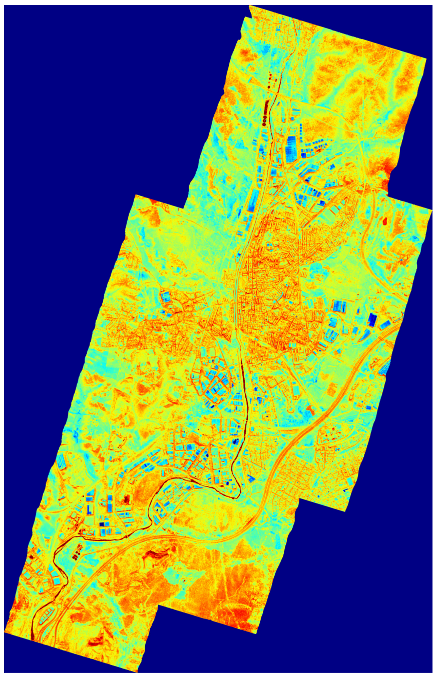
2 TEST-SITE AND MEASURING CAMPAIGN

The municipality of Rubí, with a total area of about 35 km2, is the second largest industrial district in Catalonia (Spain). In an attempt to generate an energy efficiency map of the industrial premises, the whole municipality was flown with the TASI sensor in the framework of a pioneering project called Rubí-Brilla. The project aims to make the town a reference, both at national and international scale, for energy efficiency and renewable energy use in industrial, commercial and domestic scenarios. Among the specific strands of work planned by the project, there was the thermal characterization of a set of selected industrial premises using remote sensing. Accordingly, two TASI datasets were acquired over the whole municipality area on February 5th 2013. The two acquisition processes were carried out at 12am and 6am, which roughly correspond to the times when most of the product chains of the area are idle and resumed, respectively. A sketch of the flight plan defined to cover the whole municipality is shown in Fig. 1. The main flight and sensor parameters are summarized in Table 1.

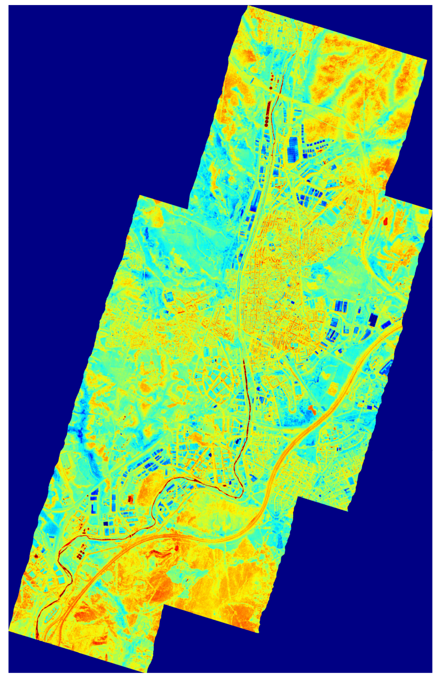
3 DATA ANALYSIS

A temperature geocoded image was retrieved from each flight track using the NCEP atmospheric profile [Barsi, 2003] tied to the ground information provided by the Cerdanyola del Vallès automatic weather station (5 km form Rubí downtown), and a version of the TES technique tailored to TASI spectral properties [Pipia, 2013]. Next, the five partially overlapped maps retrieved from each flight were mosaicked. The final temperature mosaics are shown in Figure 2a and 2b, respectively, whereas the temperature gradient map is shown in Figure 2c. Concerning the emissivity information, a noise-reduced hyperspectral map was calculated by invoking the time-stationarity of this parameter over man-made objects and averaging the two profiles available for each pixel of the imaged scene. An example of the result is provided with the image in Figure 2d, representing an RGB composition of the emissivity information at 9.6μm, 8.6μm and 8.2μm.

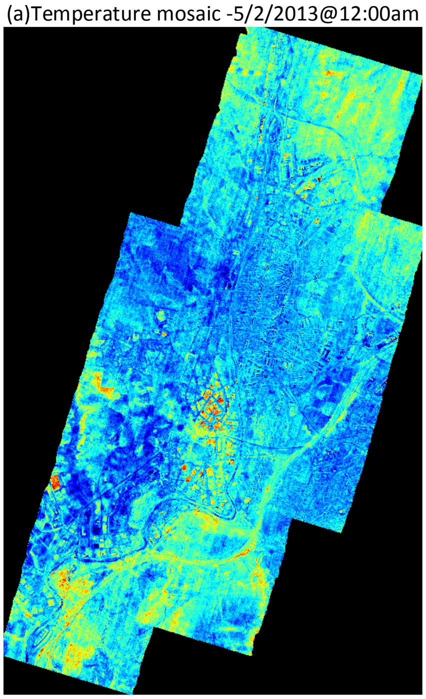
The thermal maps were compared on a pixel-by-pixel basis to detect changes in the roof temperature patterns that might be related to heat-loss fluxes. The study was applied to the 22 industrial facilities participating to Rubí-Brilla project. The temperature gradient ΔT was labelled as low, medium or high if $\Delta T<1.5ºC$, $1.5ºC<\Delta T<3ºC$ or $\Delta T>3ºC$, respectively. Note that this segmentation was fixed after examining the overall thermal behaviour within the industrial district. The collection of images shown in Figure 3 provides an example of premises belonging to the



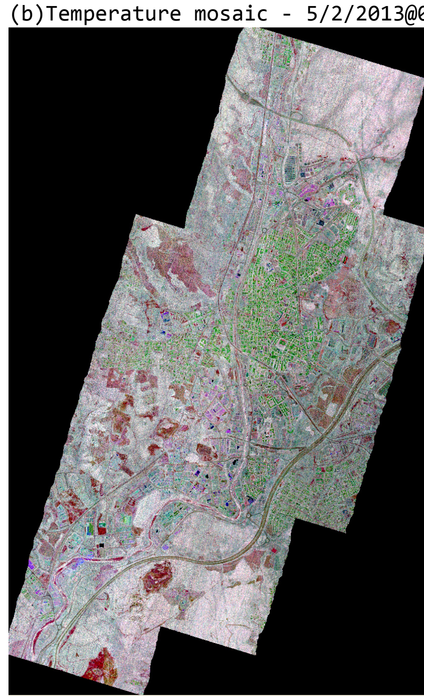
(a)Temperature mosaic -5/2/2013@12:00am



(b)Temperature mosaic - 5/2/2013@06:00



(c)ΔT mosaic: T@6:00am - T@12:00am



(d)<ϵ> mosaic:[ϵ@6:00am + ϵ@12:00am]/2

Figure 2 – Mosaicks of temperature Mosaics in Rubí at 12am (a) and 6am (b), temperature gradient (c) and of emissivity at 9.6 μm (red), 8.6 μm (green) and 8.2 (blue) (d).

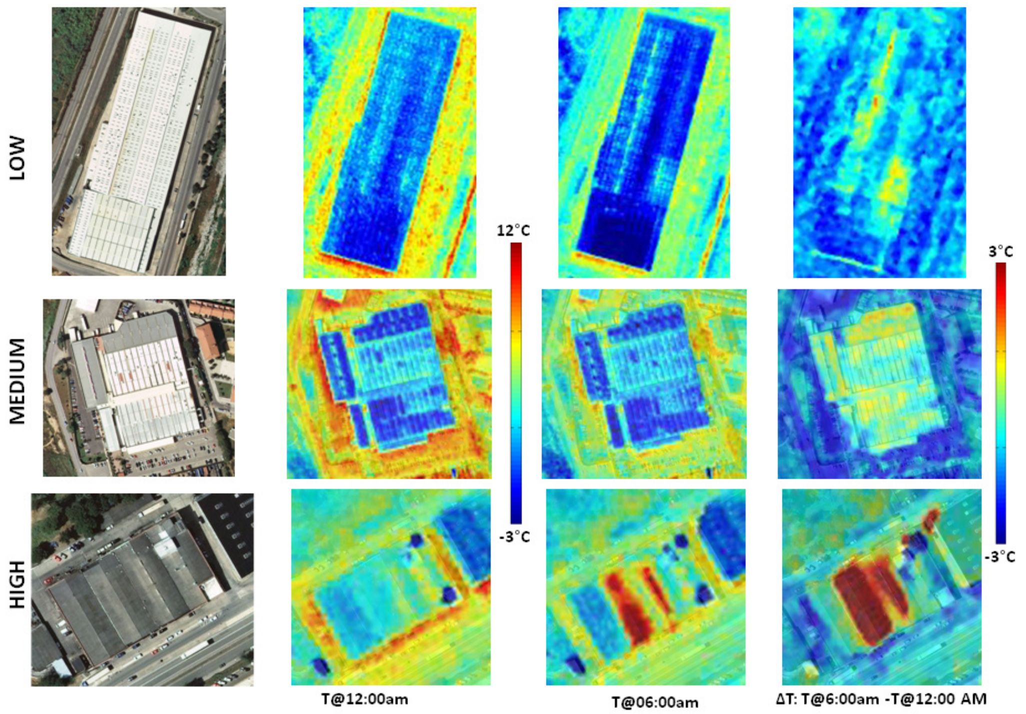


Figure 3 – Examples of industrial estates belonging to low (up), medium (centre), and high (bottom) temperature gradient classes.

three classes. Concerning the production activity carried out within each building, the low gradient case corresponds to the production of electric equipment, the medium gradient case to chemical products and the high gradient case to plastic part manufacturing.

In order to stress the existence of possible relationships between thermal behaviours and cover materials, the hyperspectral emissivity information was looked into. The areas within the same roof showing different emissivity features were detected using the Principal Component Analysis (PCA). Essentially, this technique makes it possible to reduce the hyperdata spectral dimension by transforming a set of observations of possible correlated variables (the spectral bands) into a set of values of linearly uncorrelated variables, through the maximization of the statistical variance. Accordigly, the RGB image obtained from the first three PCs was used to create a mask grouping all the pixels within the same cover showing a homogeneous behaviour. The rationale is that each group should account for a specific cover material. Afterwards, a spatially averaged 32-band emissivity signature was calculated for each group of pixels detected within the same cover. An example of the study carried out for each of the 22 industrial facilities is shown in Figure 4.

PCA stressed the heterogeneity of materials that are often present within the same cover, independently of the indoor production activity. This result was confirmed by the survey carried out by ETSEIB of Universitat Politècnica de Catalunya (UPC) in the framework of Rubí-Brilla. Yet, covers labelled by the survey the same way, for example metal sheet, turned out to show different spectral signatures, bringing out the complexity of the material classification task to be carried out and the need of more exhaustive ground-truth information. Besides, additional information about building inside temperature becomes essential

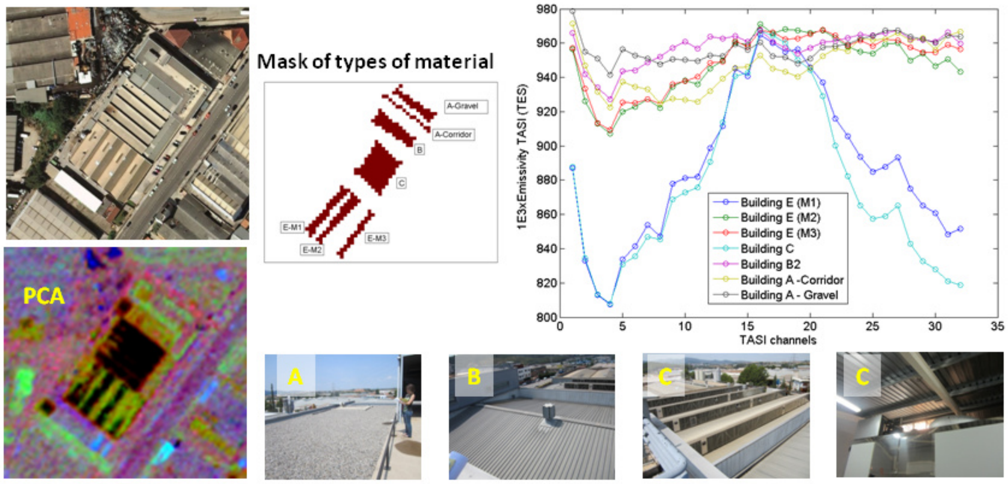


Figure 4 – Example of industrial facility cover in Rubí. RGB image from PCA is used to detect homogeneous areas and create a mask to estimate spatially-averaged 32-band emissivity profiles accounting for different materials.

to work out a quantitative descriptor of the energetic efficiency associable to each industrial building.

4 CONCLUSIONS

The two night TASI datasets acquired with a time-span of approximately 6 hours, made it possible to detect industrial building heat-loss through the estimation of the absolute temperature gradient, and discriminate cover materials using hyperspectral emissivity profiles. In-situ information concerning the material types is now required to create a hyperspectral TIR library for either supervised or non-supervised cover classifications. By cross-checking this information with building roof temperature gradient (TASI) and inside temperature gradient (related to specific production activities), it will be possible to quantitatively describe the cover thermal insulation, and provide valuable recommendations for saving production energy and, hopefully, achieving a more efficient management of the industrial buildings.

5 REFERENCES

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