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High-resolution spectral mapping of urban thermal properties with Unmanned Aerial Vehicles

Niki Gaitani [a,*], Ingunn Burud [b], Thomas Thiis [b], Mat Santamouris [a,c]

[a] National Kapodistrian University of Athens, Group of Buildings Environmental Studies, Building of Physics-5, University Campus, 157 84, Athens, Greece
[b] Norwegian University of Life Sciences, Department of Mathematical Sciences and Technology Campus Ås, P.O Box 2003, 1433 Ås, Norway
[c] The Anita Lawrence Chair, High Performing Architecture, School of Built Environment, University of New South Wales, Sydney, Australia

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ABSTRACT

The integration of microclimatic information and physical properties of the materials into urban design is essential for adequately addressing the challenges related to climate change and to adaptation of urban environment to new climatic loads. Especially, the thermal and optical properties of materials used in the urban fabric play a fundamental role in determining the microclimate and building's energy balance. The present research approach aims at analyzing the thermal characteristics of the materials and the surface temperature distribution using airborne multispectral imaging sensors mounted on Unmanned Aerial Vehicle (UAV). Aerial surveys and in-situ measurements have been carried out in April 2016 at the Municipality of Ymittos in Athens (Greece). The applied multi-sensory survey included high resolution imaging of the materials in the visible and near infrared (VIS/NIR) wavelength region and IR part of the spectrum. The images have been analysed to form maps of surface temperature distribution and of material properties. The derived thermal maps show the changes in surface temperatures of the urban materials during a diurnal heating cycle. In addition, ground measurements of VIS/NIR reflection and albedo from the survey area were obtained and an albedo map and a map of apparent thermal inertia were derived. Thermal scanning of the asphalt in the area, allowed the estimation of the state of decay due to weathering and traffic. The combined maps of surface temperature, albedo and apparent thermal inertia give new perspectives of the urban features and enhance the classification of fine urban material and the energy balance models.

1. Introduction

Over half of the global population is residing in urban areas, which are at the forefront of the climate change issue [1]. Climate projections foresee additional stress in cities through increased numbers of heat waves, more intense droughts and frequent inland floods. Consistent knowledge about cities, their structure, materials and vegetation is of high relevance for urban based adaptation and mitigation strategies [2]. The Intergovernmental Panel on Climate Change [3] notes the lack of information on urban areas at detailed spatial and temporal resolution and the importance to derive comprehensive databases on cities and develop urban climate models. To understand the urban climate a thorough consideration of many parameters, such as urban morphology, land cover, moisture availability, anthropogenic heat and material properties, is required.

Urban heat island (UHI) is the more documented phenomenon of climate change [4–6]. It refers to the occurrence of high urban temperatures compared to the surrounding rural or suburban areas. There are more than 400 cities around the world where urban heat island is experimentally documented [7], while its average magnitude may exceed 5 °C, [8]. UHI has a serious impact on the energy consumption for cooling, while it increases the concentration of pollutants and affects human health, [9].

The properties of the materials used in the urban fabric play an essential role in the energy balance, which modifies the microclimate [10]. Their thermal performance is mainly determined by the physical characteristics mainly optical and thermal [11]. The most significant factors related to radiation exchange are the albedo to solar radiation and the emissivity to long wave radiation [12]. The application of materials that present high reflectivity during summer period has gained a lot of interest during the last years as a

* Corresponding author.
E-mail address: ngaitani@gmail.com (N. Gaitani).

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mitigation strategy of the heat island effect [13]. These materials commonly named as “cool materials” are characterized by high solar reflectance and infrared emittance values resulting in lower surface temperatures. New generation of reflective materials exhibit a very high capacity to decrease the surface temperature in cities and mitigate the UHI, [14]. Cool pavements refer to a range of established and emerging materials that tend to store less heat and have lower surface temperatures compared to conventional ones [15,16]. Use of cool pavements in cities in combination with other mitigation technologies may contribute to decrease the peak ambient temperature up to 2 °C, [17,18].

The surface temperature is of prime importance, as it modulates the temperature of the lowest atmospheric layers and is central to the urban energy balance. A great deal of information on surface temperatures can be obtained through thermal remote sensing imagery, e.g. Voogt and Oke [19] give a scientific overview of thermal remote sensing capabilities in urban climate. When remotely-sensed imagery is available, valuable information can be extracted on the properties of the materials. However, as the most commonly available remotely sensed measurements are from satellites and usually have a spatial resolution of several meters, they are not always suitable for modelling microclimate effects in urban areas and on individual buildings. The development of Unmanned Aerial Vehicles (UAVs) and of small spectral imaging sensors makes it possible to obtain spectrally resolved images at very high spatial resolution in an easy and flexible way.

There is an increased interest of UAVs surveying in different scientific fields as agricultural management [20,21] civil engineering [22,23] photogrammetry [24] and atmospheric environment [25]. For urban scale the use of UAVs as a sensor platform is novel and will support microscale measurements by providing flexibility in the timing of data captured and the scale of the images obtained.

The use of infrared sensors is an important tool in many close range applications. Thermal infrared cameras (in the bandwidth 3.5 μm < λ < 14 μm) provide the visualization of thermal differences on the surface of an object [26]. Moreover, the integration of near infrared (NIR) camera (0.75 μm < λ < 3 μm), accumulates further radiometric information on the thermal properties of the materials [27] and is a well-established tool for the analysis of vegetation [28]. In addition, the Normal Difference Vegetation Index (NDVI) is widely adopted in vegetation studies [29] and ground parameters such as ground cover and surface water.

The aim of this study is to analyse the physical properties of materials at urban scale with high-resolution surveying and assess their mitigation potential. This paper presents a classification-based methodology for surface emissivity mapping and surface temperature distribution over the examined area by combing airborne data, in-situ measurements and emissivity values. The surface temperature maps and the solar reflectance map have been used to derive a map of apparent thermal inertia.

2. Description of the site

The study area was in Ymittos Municipality, which is a suburb, situated 2.5 km southeast from the centre of Athens, Greece. The typical Mediterranean climate in this area is characterized by hot, dry summers and cool, wet winters.

The study site was rehabilitated in the period 2012–2014. The central square (see Fig. 1), with the town-hall is located just north of a park of 34800 m^2 with an old abandoned industrial area of 157000 m^2 to the west. The initial pavements were made of old asphalt, concrete and dark paving materials, with albedo varying from 0.05 to 0.22. At final form 5170 m^2 of pavement and 4000 m^2 of asphalt were replaced. In total, over 9000 m^2 of cool paving coating and 555 m^2 of pavement with embedded photovoltaic panels have been applied to the area. The examined area has been selected to combine: (a) an area with a small green space, the park, (b) an area with reflective pavements, the square of Ymittos and (c) a reference area with conventional material, the surrounding neighbourhoods.

Indicative points of different materials are shown in Fig. 1: asphalt with cool coating (Point 7), marble (Point 9, 10, 11), old conventional asphalt (Point 1, 3, 5, 6), new conventional asphalt (Point 4), paving tiles (Point 8) and vegetation (Point 2).

3. Materials and data

Aerial surveys and in-situ measurements have been carried out in April 2016 at the Municipality of Ymittos in Athens (Greece). The applied multisensory survey included high resolution recordings of the materials in the visible and near infrared (VIS/NIR) wavelength region and IR part of the spectrum. The flights were performed in a predetermined pattern at an altitude of 100 m. A total of approximately 80 partly overlapping images were recorded in each flight.

An RGB camera, a rebuild RGB camera where the blue channel is replaced by a NIR channel (*Canon PowerShot* rebuild by *Maxmax.com*) and an IR camera (*Optris 640*) were used. The pixel size of the pictures varied from 8 to 80 mm depending on the type of sensor.

The RGB, VIS/NIR and IR images from the aerial surveys have been corrected for the geometric distortions (orthorectification process) [30] and then transformed to geo-referenced raster images with ERDAS Imagine [31]. A standardized grey calibration plate reflecting 60% of the solar radiation was recorded before and after each set of VIS/NIR images. Close-up images of the different materials were also performed with an RGB camera, an IR camera and the VIS/NIR camera.

Additionally, in-situ measurements were conducted under sunny, calm and clear atmospheric conditions, as listed in Table 1. Not all the measurements are used in this paper.

4. Theory and analysis

The intensity of infrared radiation, which is emitted by each body, depends on the temperature as well as on the radiation features of the surface material of the measured object. For the estimation of surface temperature, the spatial distribution of urban surface emissivity is site specific, depending mainly on vegetation and man-made materials at the area.

To classify the surface material the Normalized Differential Vegetation Index (NDVI) maps were computed from the VIS/NIR images. The formulation of NDVI allows to cope with identical patches shaded (cloud sky) and non-shaded (bright sunshine), by dividing by the sum of reflectances. The NDVI algorithm subtracts the red reflectance values from the NIR and divides it by the sum of NIR and red bands according to the equation:

$$\boldsymbol{NVDI} = (\boldsymbol{NIR} - \boldsymbol{R})/(\boldsymbol{NIR} + \boldsymbol{R}) \quad (1)$$

where NIR and R are the reflectance values in the near infrared and red wavebands, respectively.

A classification map of four materials, water, asphalt, soil and vegetation (Fig. 2), was created from the NDVI map and a value of the emissivity was assigned to each class of materials [32]. The material classes have been used to calibrate IR measurements to represent actual surface temperature. In total four surface temperature maps were obtained, early morning (7:40 a.m.), late morning (10:15 a.m.), midday (13:30 p.m.) and evening (20:20 p.m.) (displayed in Fig. 3).

Albedo (or solar reflectivity) is defined as the fraction of incident radiation that is reflected by a surface and it is measured on a scale