Operational light source and luminance determination methodology by using hyperspectral and mapping cameras at very high spatial resolution

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Introduction

Nocturnal light pollution is a side effect of industrial civilization and accounts for excessive, misdirected or undesired artificial light produced by dwellings, factories, offices, sport fields, billboards, street lights and so on. Metropolitan areas account for 75% of the world's energy consumption and much of its CO2 emissions. For instance, in Spain, in some towns and cities, public lighting is responsible for 50% of power consumption. Thus, street lighting is one of the sectors with a larger potential in energy saving (between 30% and 40%): lighting and management systems are nowadays being developed and improved, by using more efficient lights with less energy consumption.

Reliable methods to quantify the amount of artificial light radiation are a prerequisite to detect light/energy waste and to assess the effectiveness of policies and actions. Current auditing processes based on field campaigns are time consuming, thus costly and tedious. In this work, remotely sensed night-lights observations are used to distinguish different sources of lighting depending on their spectral signature and to quantify their level of light emission.

Concerning data acquisition as a part of such methods, space-borne imagery provides a moderate spatial and spectral resolution (currently available from instruments on board satellites and space platforms, such as the data taken by DMSP and SUOMI satellites or from the International Space Station). Such data have limited spectral bands and coarse spatial resolution, and the dynamic range of the sensors is optimized for daytime rather than nocturnal capture. Field campaigns are unable to provide a synoptic view over a large area. Accurate quantification and characterization of artificial light radiated at ground level from remote sensing imagery requires high spectral and spatial resolutions, with a high dynamic range. Images with these characteristics can be achieved with airborne hyperspectral imaging spectrometers.

At the Institut Cartogràfic i Geològic de Catalunya (ICGC) we have developed a methodology to fusion data simultaneously recorded with a hyperspectral sensor (an AISA Eagle II from SPECIM), which combines synoptic view with multiple narrow spectral bands, and a digital photogrammetric camera (a DMC-I from Z/I-Hexagon). As a result we are providing to local authorities luminance maps at a resolution up to 0.25 cm and maps of main source of lights (incandescent, mercury vapor, high pressure sodium vapor, metal halide and light-emitting diode-LEDs).

Sensors and Data acquisition

AISA Eagle II

The AISA Eagle II is a hyperspectral VisNIR pushbroom imager with a reflection grating and a two-dimensional CCD (charge coupled device) solid-state array detector, manufactured by SPECIM. The instrument operates by looking down in a fixed direction and imaging successive lines of the flown scene, building up a two-dimensional image as the platform moves forward. One dimension of the CCD covers the across-track spatial direction (1024 spatial pixels); the other one accounts for the spectral domain (configurable up to 256 bands covering the spectral range 400-1000 nm).

FOV [deg]	37.7º
# of FOV pixels	Configurable 512 or 1024
# of spectral pixels	Configurable up 256
Spectral range [nm]	400-1000
Focal Length [mm]	17.8
GSD [m] @ 2500m	1.5
Swath overlapping (side lap)	40%

DMC-I

DMC is a high-resolution photogrammetric frame camera, manufactured by Z/I imaging (currently Hexagon), which simultaneously captures one high-resolution (HR) panchromatic and four low-resolution (LR) multi-spectral (red, green, blue and near-infrared) images. The across-track and along-track ratio between multispectral and panchromatic imaging is 1:4. The high resolution image is the result of mosaicking four subimages acquired by four inclined panchromatic camera heads. Each of them covers approximately a quarter of the final image, called virtual image. The four low resolution multi-spectral images in the red, green, blue and near-infrared color bands are acquired with four additional nadir-looking camera heads with a focal length of 25 mm. Note that the four images completely cover the virtual high resolution image.

FOV [deg]	69.3º (ACT) x 42º(ALT)
# of FOV Pixels (HR)	13824x 7680
# of FOV Pixels (LR)	3072x1920
# of Spectral bands	1(panHR) /4LR
Focal Length [mm]	120(pan)/25(LR)
GSD [m] @ 2500m	0.25(panHR)/1(LR)
Swath overlapping (side/end lap)	70%/70%

Data acquisition

Data are acquired in a single nocturnal flight where sensors are operated simultaneously in an airborne platform, which is able to carry both sensors. In order to avoid natural light sources (moon light), flight is performed close to the New Moon phase or the nights when moon has been already set. Notice that, due to safety reasons according to aerial control authorities, nocturnal flights have some operational restrictions that may limit the resolution of the luminance map..

- Night Flight
  - Flying safety restrictions
  - Moon-free nights avoiding extraterrestrial light
  - Preferable dates in winter

	AISA Eagle II	DMC-I
# pixels	1024	13824 x 7680
# spectral bands	126	PanHR/Color4LR
Spectral range [nm]	404.08 – 996.31	VIS/NIR
Flying height	2300	2300
GSD [m]	1.5/2.8	0.23 (pnaHR)/1(LR)
Image overlap	40%	70%/70%

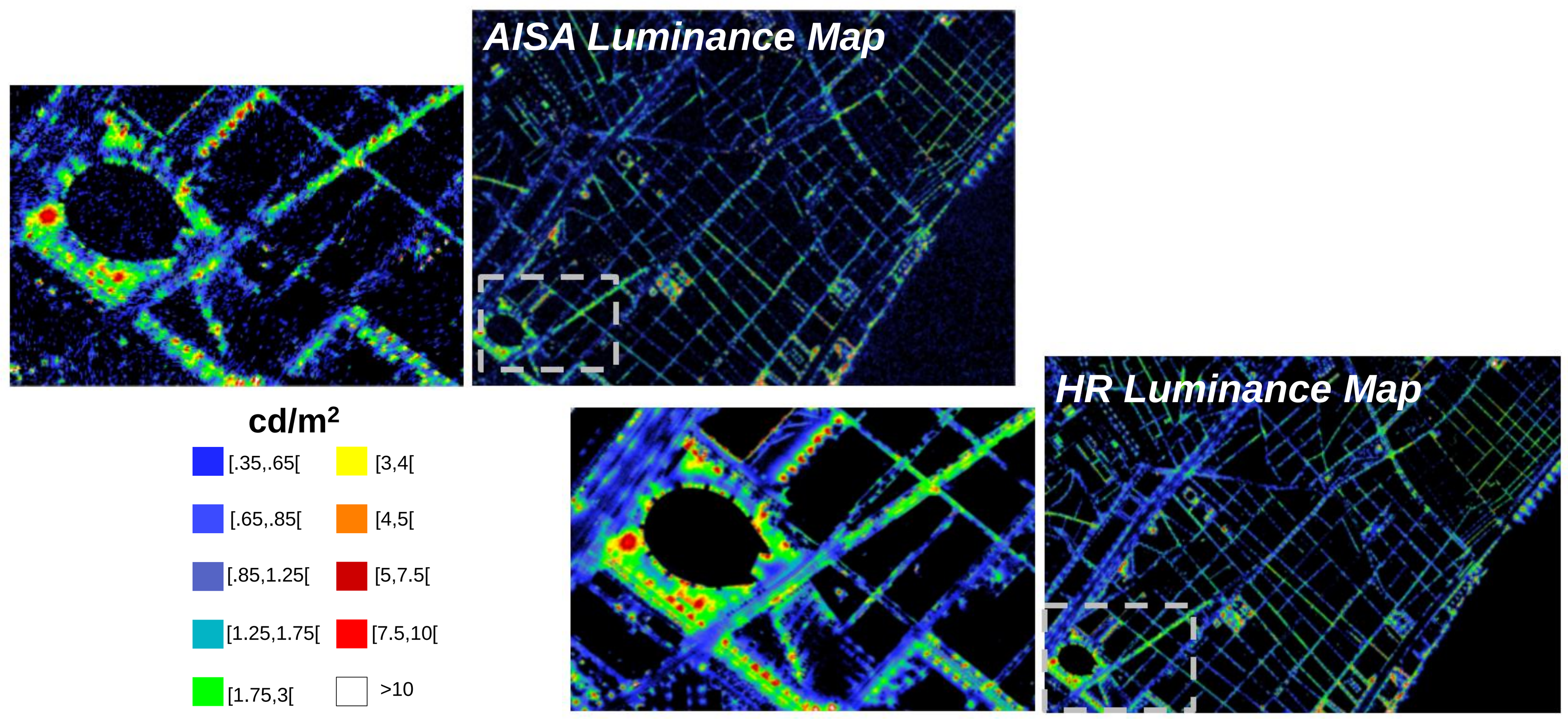
HR Luminance Map [4]

Luminance Map (retrieved from Hyperspectral sensor)

For each pixel, the VisNIR sensor collects a spectral sampling of the radiation in 400-900nm spectral range emitted by the surface. As luminance map must represent how the human visual system perceives the radiance of light at ground level, the radiance values of the 126 bands must be converted to luminance values at ground level and then combined in a way which mimics the visual perception of human beings. Luminance is a photometric measure which describes the amount of light that is emitted by a unit of area and is expressed in cd/m2. The spectral sensitivity of the human visual system is described by the photopic luminosity function defined by the Commission Internationale de l'Éclairage (CIE). This function indicates the sensitivity of human eye to incoming light radiation at different wavelengths. The conversion from measured radiance to luminance at ground level is performed in several steps. Firstly, a radiometric calibration converts the values (digital numbers) captured by the VisNIR sensor into radiances at flying height. Then, these radiances are transferred to radiances at ground level by compensating for atmospheric hyperspectral attenuation and combining the 126 radiances recorded per pixel using the photopic luminosity function. Finally, a low resolution luminance map of the entire area is created by mosaicking the flight tracks of the hyperspectral sensor..

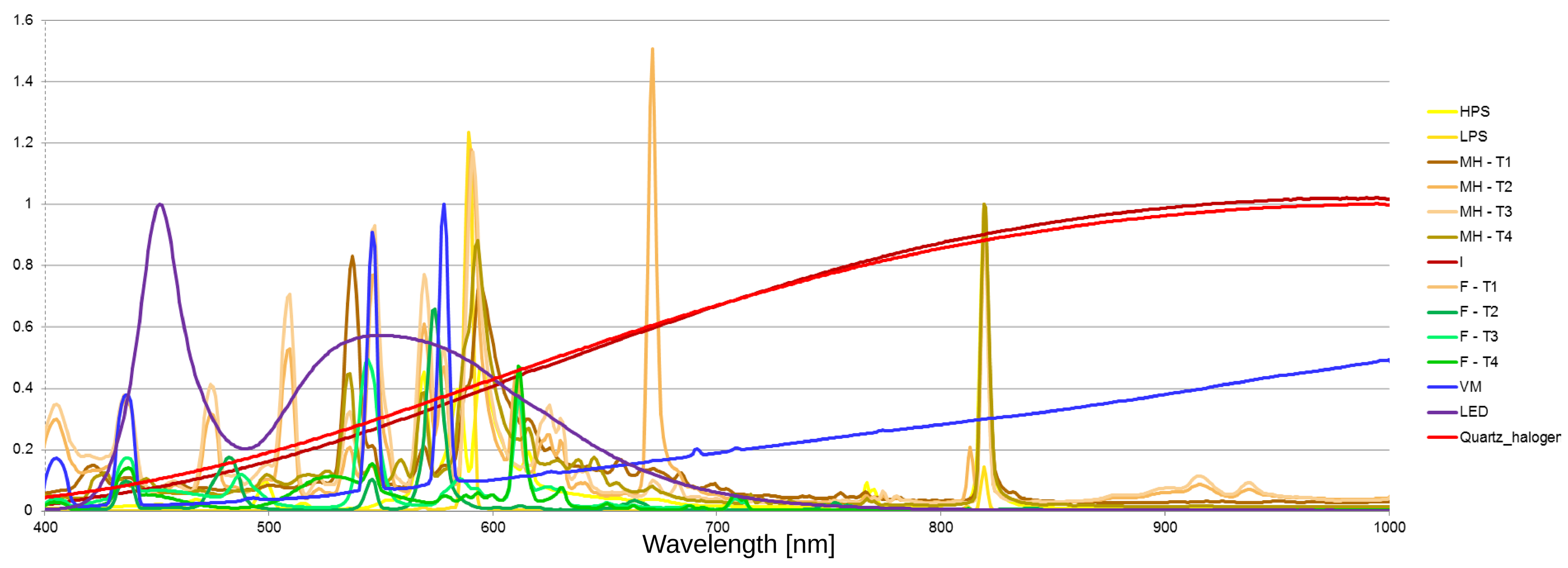
DMC and AISA data fusion

The dynamic range of the DMC panchromatic band is higher compared to the VisNIR sensor as the DMC spectral bands are much broader so that more photons can reach the charge-coupled device (CCD) in the image plane. The fusion consists of fitting the radiance values of DMC images to the VisNIR luminance map. Once this calibration process has been completed, the luminance map at 0.25m GSD can be computed from DMC imagery alone.



Light Source Type Map

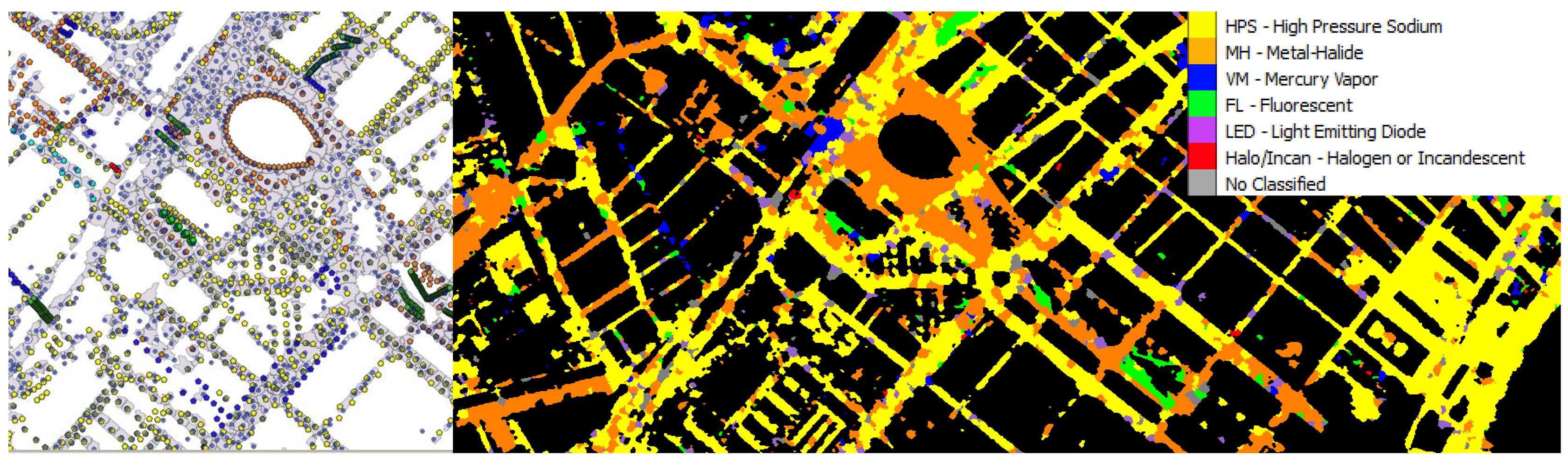
In the literature, hyperspectral and multispectral airborne sensors have been often used for nocturnal image analysis. Yet, all these studies have been focused on the detection of artificial light sources or classification based on specific spectral signature detection ([1], [2], [3] and [5]). As shown in figure below, artificial light sources have specific spectral signatures. The hyperspectral capabilities of the AISA Eagle II sensor allow deriving a set of spectral indexes focusing in particular features of the light spectral signatures, which are used to discriminate them.

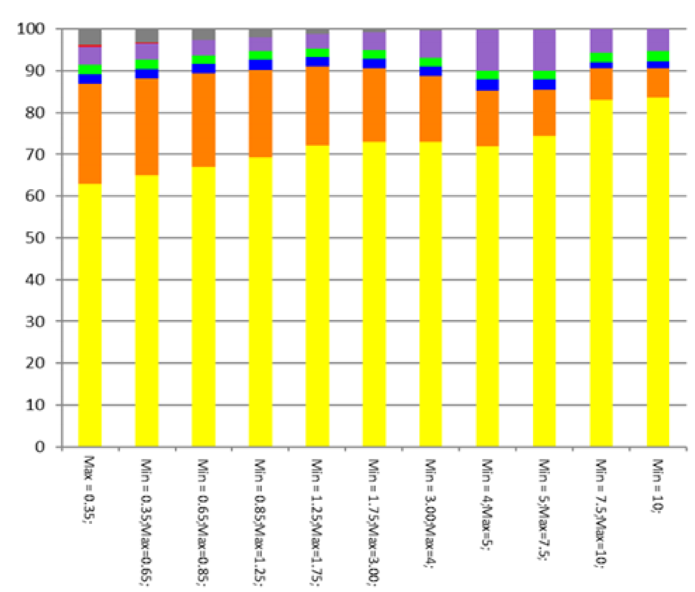


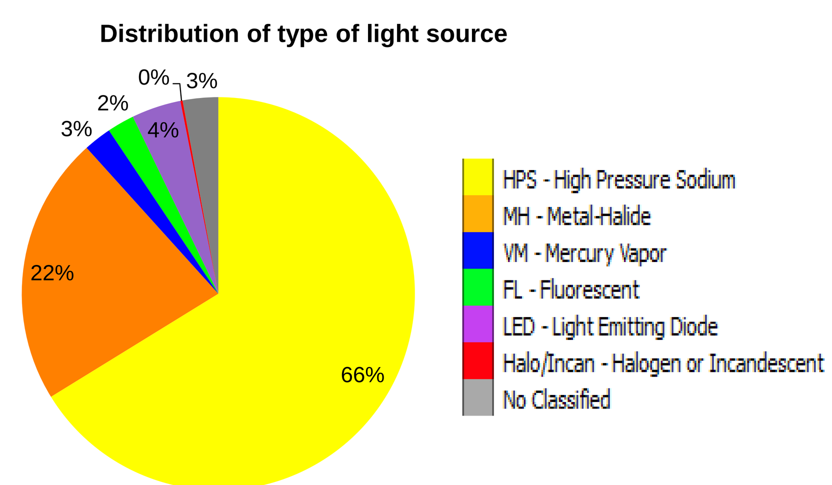
The hyperspectral instrument AISA Eagle II has been designed for recording reflected sunlight and not for capturing artificial light. Then, the relatively low intensity of artificial light at night and the limited exposure time by operational restrictions cause hyperspectral images to be affected by high noise level.

In order to overcome with this handicap, it has been perform the detection of punctual source lights and their illuminated neighborhood in the DMC nocturnal images. Such point-like source describes the position where light intensity is the highest in its neighborhood, and is likely to correspond to the lamp center.

In each neighborhood a new set of light spectral indexes is computed as a weighted (by the light intensity over the whole light intensity in the neighborhood) average of the spectral indexes derived from the AISA data. This new set of indexes is used to derive the main type of the light source in the neighborhood of the punctual source light.







Conclusions

The operational approximation of the ICGC is providing high resolution luminance maps (up to 25 cm GSD) and light source typology maps (up to 1.5 m GSD). Such maps, which are retrieved from simultaneous hyperspectral and photogrammetric acquisitions covering the entirely municipalities, are providing a synoptic view of the nocturnal urban landscape. Public and private illumination can be analyzed in order to:

- check whether policies on light pollution are fulfilled in terms of intensity (mainly excess of light emitted towards the sky due to reflection or misdirection of the lamps) or typology of light sources (mercury vapor lamps,…).
- Cross usage of typology of light versus intensity or facilities
- Periodic flights may be a tool to evaluate street lighting policies and actuations.

References

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