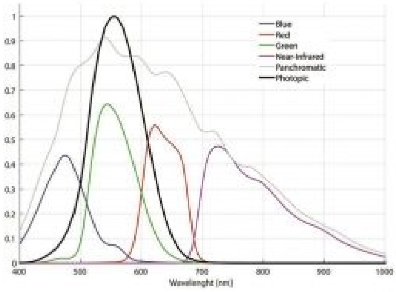
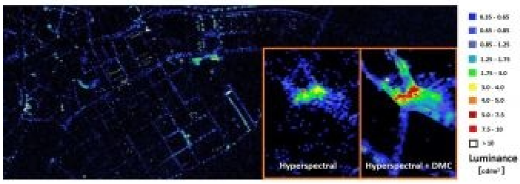
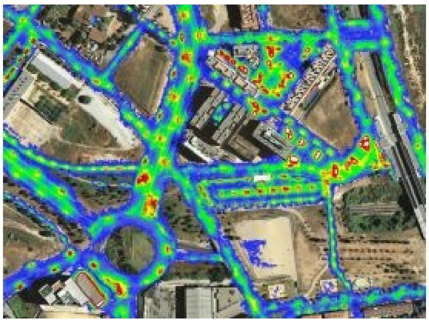
FUSING HYPERSPECTRAL DATA AND PHOTOGRAMMETRIC IMAGERY

Mapping Nocturnal Light Pollution







Artificial light in urban conglomerates causes nocturnal light pollution. Excessive light radiation is expensive as it wastes energy and not only impacts the environment but may also harm human health. Authorities are showing a growing interest in quantifying the amount of artificial light radiated at ground level in their jurisdiction. A recent project in Spain explored an approach based on fusing simultaneously acquired hyperspectral data and photogrammetric imagery. The resulting luminance maps are accurate and have a high spatial resolution.

(By Jordi Corbera, Vicenç Palà and Fernando Pérez-Aragüés, Spain)

Nocturnal light pollution is a side effect of industrial civilisation and accounts for excessive, misdirected or undesired artificial light produced by dwellings, factories, offices, sport fields, billboards, street lights and so on. 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. With respect to the data acquisition part of such methods, space-borne imagery has limited spectral bands and coarse spatial resolution, and the dynamic range of the sensors is optimised for daytime data acquisition rather than for data capture at night. Field campaigns are time-consuming, thus costly, and unable to provide a synoptic view over a large area. Accurate quantification of artificial light radiated at ground level from the air requires high spectral and spatial resolutions while the spectral bands have to be recorded with a high dynamic range. To obtain images with these characteristics, the authors fused data simultaneously recorded with a hyperspectral sensor, which combines synoptic view with multiple narrow spectral bands, and a digital photogrammetric camera.

Sensors

The airborne approach developed by the authors to overcome the limitations mentioned above uses the AisaEAGLE-II hyperspectral sensor from SPECIM, configured to acquire 128 bands in the visible and near-infrared (VNIR) part of the electromagnetic spectrum covering the range 406.3nm to 993.8nm. The ground sampling distance (GSD) of this VNIR sensor is 1.5m. Light sources which may disturb the observations can be avoided by selecting time windows, such as new moon phase. Most bands have a low signal-to-noise ratio (SNR). Furthermore, the approach uses a digital mapping camera (DMC) from Z/I (currently Hexagon), capturing the panchromatic band with 0.25m GSD and the blue, green, red and near-infrared bands with 1m GSD. This photogrammetric camera has been developed for high-accuracy mapping.

Area

The study area used to test the approach covered three urbanised municipalities near Barcelona, Spain, which have been promoting efficient artificial lighting policies in recent years. They funded the study, which was carried out by Institut Cartogràfic i Geològic de Catalunya (ICGC). To capture the 150km^2 area at maximum spatial resolution, the minimum altitude permitted for night flights over urban areas was used. The area was captured in 19 flight tracks from 23:00h on 18 October 2014 until 02:00h the next day, a date which was chosen to avoid recording moonlight. The aircraft flew at 2,200m above ground level (Figure 1).

Luminance

For each pixel, the VNIR sensor collects a spectral sampling of the radiation in the blue, green, red and near-infrared range emitted by the surface. During moon-free nights it may be assumed that the radiance is due to artificial illumination alone. Most studies suffice with adding the radiance values of the diverse hyperspectral bands – 128 in this case – recorded at flying height. However, this project aims to mimic how the human visual system perceives the radiance of light, or brightness, at ground level. For this purpose the radiance values of the 128 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 candela per square metre (cd/m^2). 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 (Figure 2). The conversion from radiance values to luminance values at ground level is performed in several steps using humidity values and other atmospheric observations. Firstly, a radiometric calibration converts the values (digital numbers) captured by the VNIR sensor into radiances at flying height. Then, these radiances are transferred to radiances at ground level by conducting atmospheric corrections and combining the 128 radiances recorded per pixel using the photopic luminosity function. Finally, a luminance map of the entire area is created by mosaicking the flight tracks (Figure 3).

Fusion

Up to this stage only the data recorded by the VNIR sensor has been explored and the luminance map looks blurred compared to the map created using both hyperspectral and DMC data, as the insets of Figure 3 demonstrate. Even individual street lights become detectable after fusion. The dynamic range of the DMC panchromatic band is higher compared to the VNIR sensor as the DMC bands are much broader so that more photons can reach the charge-coupled device (CCD) in the image plane. As a photogrammetric instrument the DMC has been designed for recording reflected sunlight and not for capturing artificial light. The relatively low intensity of artificial light causes multispectral and panchromatic DMC images to be affected by band-dependent noise and residual vigneting. These undesired effects have been eliminated through spectral filtering. The fusion consists of fitting the radiance values of the blue, green, red and near-infrared bands of DMC images to the VNIR luminance map. Once this calibration process has been completed, the luminance map can be computed from DMC imagery alone. A linear combination of the blue and green DMC images provided the best fit and resulted in a luminance map with 1m GSD (Figure 4). The two insets in Figure 3 clearly demonstrate the differences in noise levels, sensitivities and spatial resolutions between the hyperspectral luminance map and the luminance map obtained from fusing hyperspectral and DMC data. Finally, a luminance map at 0.25m GSD was created by searching for the best fit between the panchromatic, green and blue DMC bands and the luminance map. The best results were obtained using panchromatic and green bands. Figure 5 shows the resulting luminance map superimposed on the orthoimage.

Acknowledgements

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Further Reading

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Figure Captions

Figure 1, *Flight plan.*

Figure 2, *The photopic curve (black line) together with the spectral sensitivity of DMC bands.*

Figure 3, *VNIR Luminance Map obtained from hyperspectral VNIR imagery, GSD 1.5m. Pixels with a luminance <0.35cd/m*^{2} are black. *The two insets cover the area outlined in orange in Figure 4.*

Figure 4*, Luminance Map obtained from fusing VNIR and DMC data, GSD 1m. Legend as in Figure 3.*

Figure 5, *Detail of the final Luminance Map, GSD 0.25m. For pixels with a luminance <0.35cd/m*^{2} *the underlying orthoimage is shown. Legend as in Figure 3.*