Remotely sensing changes in lighting infrastructure of cities

Alexandre Simoneau, Martin Aubé

Université de Sherbrooke

DARK & QUIET SKIES

Abstract

Anthropogenic light emissions have been known to disrupt the quality of astronomical observations. Moreover, we now know that they also have significant impacts on ecology and human health. One challenge in studying artificial light at night is determining the emission properties of anthropogenic light sources on a large scale. Current spaceborne sensors lack the spectral and angular resolution needed to properly assess luminous city emissions. The present project proposes a method to fully evaluate these emissions using digital cameras mounted on airborne (and potentially spaceborne) platforms. This allows for determining the angular and spectral radiance of cities and monitoring their temporal changes, which is crucial to understand and control them.

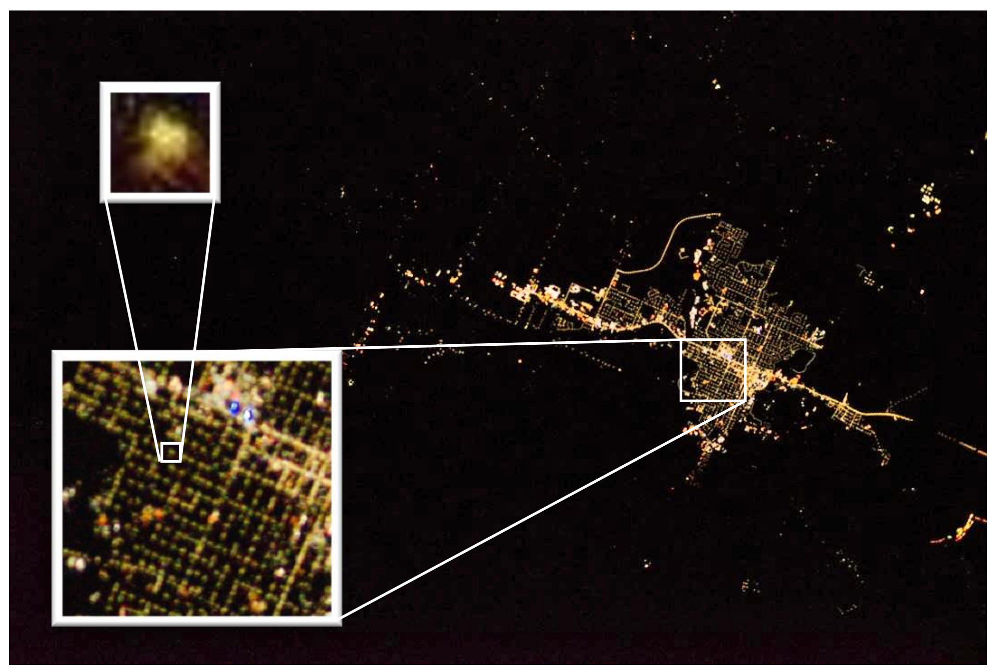

Figure 1: Airborne image of the city of Timmins, ON, Canada. Taken on August 25, 2019, from a digital camera onboard a high-altitude balloon. With a spatial resolution of ~8 m, individual light sources can be identified. The colour information allows for identification of lighting technology. Close up on the source analyzed in the present work.

Objectives

The goal of this work is to **develop a set of simple methods to calibrate a digital camera** for usage in dim settings. These methods will allow the development of airborne measurement platforms capable of remotely monitoring the properties of lighting systems and their changes over time.

The complete calibration of a digital camera requires multiple calibration procedures in order to fully account for all the physical interactions of the optics of the system. The calibration steps include subtracting a **dark frame**, handling **cosmic ray events** on the sensor, correcting for the **non-linear response** of the detector, obtaining a **flat field** to properly assess the vignetting and darkening of the obtained images due to the optics of the system, and potential dust present on the sensor or in the lens apparatus, determining the **photometric relation** between the measured brightness values and the irradiance of the observed objects, and evaluating the **geometric distortions** present in the images, which is especially important for ultra wide-angle fisheye lens.

The present work shows the results of these calibration methods for a SONY a7s equipped with a SAMYANG 50 mm T1.5 lens. This camera was placed on an airborne platform that flew 30 km above the city of Timmins, ON, Canada and took a series of images of the upward light emission of the city during the night of August 25, 2019. One such image is shown in Figure 1.

Results

The first calibration step is to remove the effects of dark currents in the images. They are background values caused by heat and bias in the device, that are removed by subtracting the average of multiple dark frames taken in the same conditions as the images being calibrated while the lens is covered to block incoming light.

High energy particles can hit the sensor and cause highly localized groups of seemingly bright pixels. These events can be detected using Laplacian Edge Detection algorithms [1] and removed by replacing them with the neighbouring average value.

The output of a digital sensor is not perfectly proportional to the input signal. The non-linearity of the sensor is established by taking images of a constantly lit surface with various exposure times. The data in Figure 2 shows the non-linearity of the sensor.

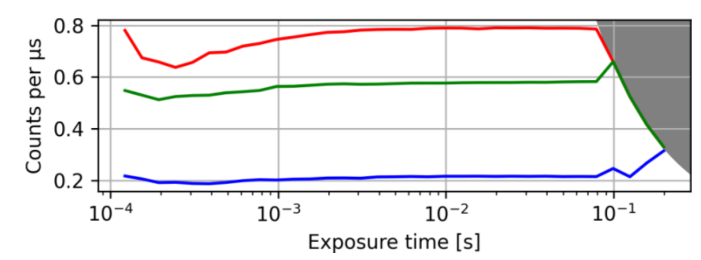

Figure 2: Digital number average rate for various exposure times. The three curves are for the three colour channels of the camera: red, green and blue, from top to bottom. The different levels are caused by the colour of the light source used for the test. The grey zone is the saturation area. One can notice the decrease in sensitivity for short exposure times.

Due to the optics of the lens, the corners of an image typically receive less light than the centre. To correct this effect, an image of a perfectly uniformly lit surface is captured. Multiple images of a surface taken at various angles can simulate a larger and more uniformly lit one, improving the quality of the calibration.

Figure 3: The camera is attached to a motorized mount that allows taking multiple images of the reference surface at different viewing angles, thereby simulating a larger, more uniformly lit surface.

The relationship between the digital count obtained from the sensor and the irradiance of the observed light sources is measured by taking photographs of a source of known spectral emission. Stars can be used for this purpose as their spectral light emissions are well known [2]. The effect of the atmosphere is taken into account based on data from the Aerosol Robotic Network.

Finally, the geometric distortions caused by the lens are evaluated by taking a picture of a star field. The positions of the stars are well known and can be used as reference.

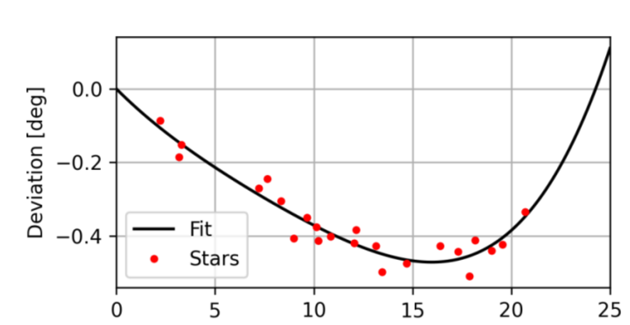

Figure 4: Deviation from a perfect equirectangular lens observed for a set of stars in the Andromeda constellation and the resulting polynomial fit.

Results (cont.)

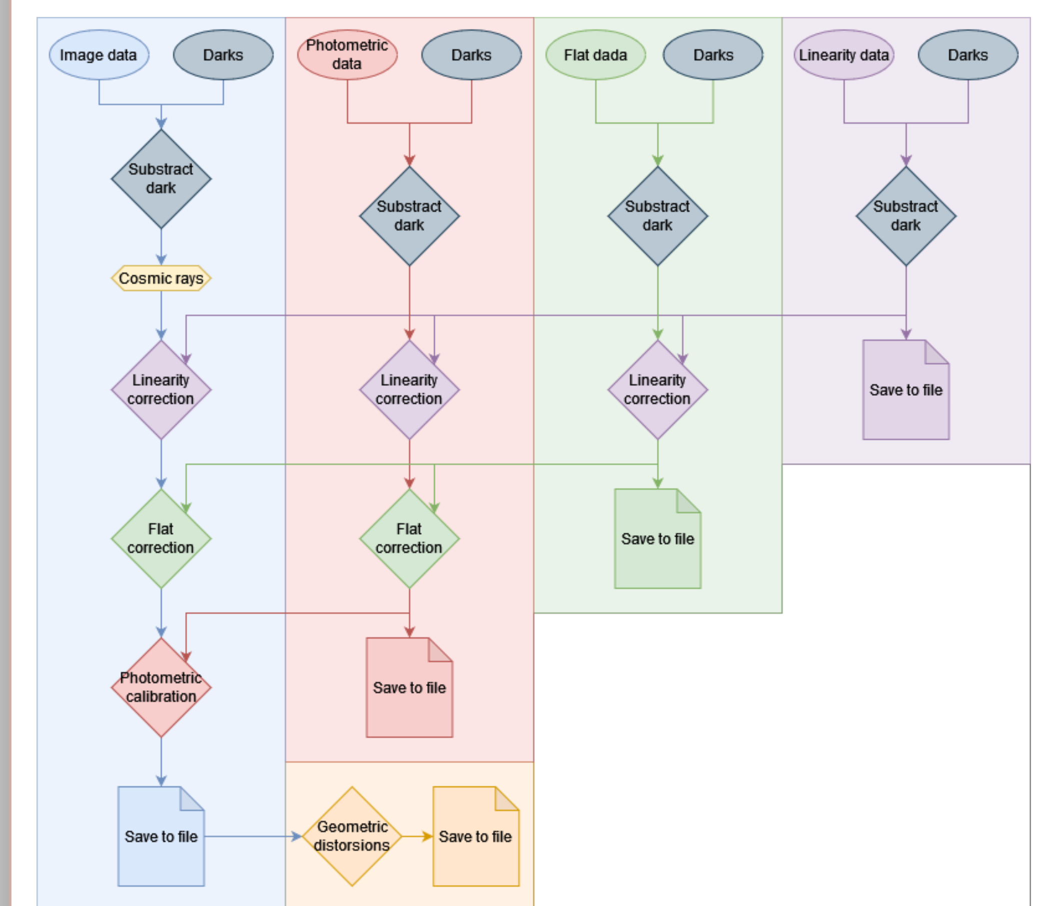

Figure 5: Complete calibration pipeline.

Having a multispectral calibrated imaging airborne system allows remote detection of the properties of the lighting infrastructure of cities. The position, brightness and colour of the sources are easily obtainable, and overlapping images allow sensing their angular emission function. One such function for a single source is shown in Figure 5. The interesting value is not the average but the maximum. This is because camera sensors can only measure a single colour for each pixel and interpolation techniques are used to fill the gaps. For small sources, this causes some of the light to be missed between the pixels. Here, the value 3 standard deviation above the maximum is used as it will be above the measured values 99.7% of the time.

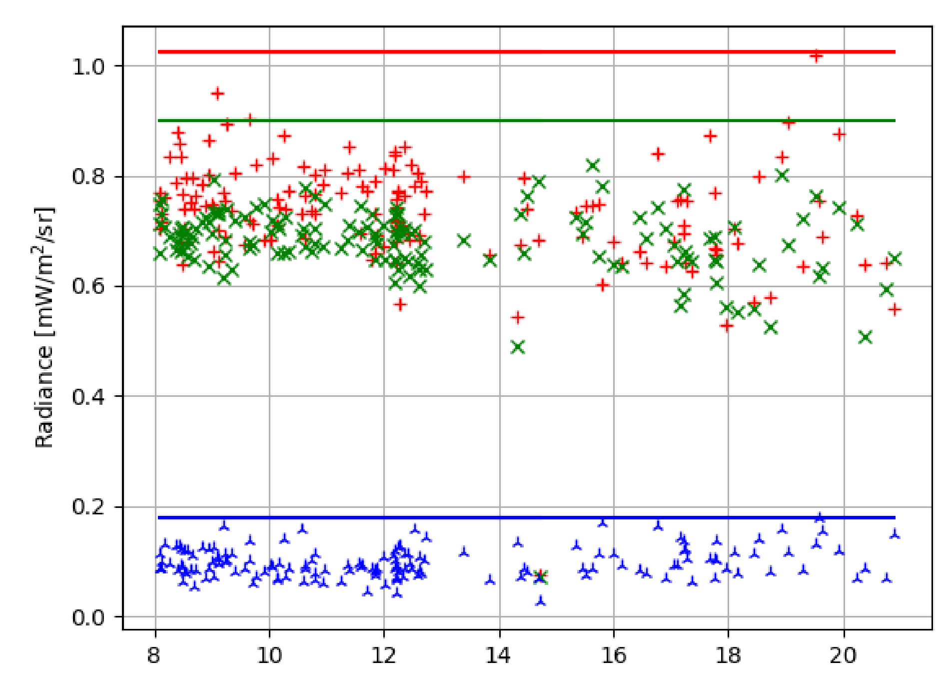

Figure 5: Angular emission of a single light source in the city of Timmins. The lines correspond to the value 3 standard deviation above the average for each band.

The emission is mostly constant with regard to the viewing angle, indicating that the camera is imaging the ground illumination caused by the source. The colour information can then be used to identify the spectral technology by looking at the ratio of the different colour bands [3].

Results (cont.)

The flux Φ of a lamp in a spectral band can be estimated from the observed radiance R using

$$\Phi = \frac{R\pi S}{\rho T}$$

where S is the surface of the observed pixels (~70 m²), ρ is the ground reflectance (~0.07 for asphalt) and T is the atmospheric transmittance (~0.8). This gives a lamp flux in the green band of about 3.5 W. This is the interesting value to track, but for validation purposes, we can go back to the electric wattage of the globe by making some assumptions. Assuming the lamp is a high-pressure sodium based on its colour, whose luminous efficiency is about 0.15 W/W and that emits about 1/3 of the light in the green band, the electric wattage of the bulb would be 70 W, which is typical for streetlights of this kind. While this number is not the most meaningful to track, it can be used to compare with ground-based inventory of the lighting infrastructure as a validation method.

Conclusion

The properties of the lighting infrastructure are obtainable from airborne sensors such as the one used in this work. The colour information allows for estimating the lighting technology used, and the angular emission function is directly measured by imaging the sources from various angles. The flux of the sources are obtainable in each of the spectral bands of the sensor.

Once the properties of the lighting infrastructure are known, it is possible to follow the evolution of the light emissions of a city by repeating the experiment at a later time. Such monitoring makes evaluating global and local trends in lighting possible, and opens the door for the enforcement of lighting regulation on a large scale. These efforts may contribute to the preservation of the night for all.

References

[1] P. G. van Dokkum, Cosmic-Ray Rejection by Laplacian Edge Detection. Publications of the Astronomical Society of the Pacific, 113(789):1420–1427, 2001.

[2] N. Cardiel, J. Zamorano, S. Bará, A. Sánchez de Miguel, C. Cabello, J. Gallego, L. García, R. González, J. Izquierdo, S. Pascual, and et al. Synthetic rgb photometry of bright stars: definition of the standard photometric system and ucm library of spectrophotometric spectra. Monthly Notices of the Royal Astronomical Society, 504(3):3730–3748, 2021.

[3] A. Sánchez de Miguel, C. C. M. Kyba, M. Aubé, J. Zamorano, N. Cardiel, C. Tapia, J. Bennie, and K. J. Gaston. Colour remote sensing of the impact of artificial light at night (i): The potential of the international space station and other DSLR-based platforms. Remote Sensing of Environment, 224:92–103, 2019.

[4] M. Aubé, and A. Simoneau, New features to the night sky radiance model illumina: Hyperspectral support, improved obstacles and cloud reflection. Journal of Quantitative Spectroscopy and Radiative Transfer, 211:25–34, 2018.

[5] A. Hänel, T. Posch, S. J. Ribas, M. Aubé, D. Duriscoe, A. Jechow, Z. Kollath, D. E. Lolkema, C. Moore, N. Schmidt, H. Spoelstra, G. Wuchterl, and C. C. M. Kyba. Measuring night sky brightness: methods and challenges. Journal of Quantitative Spectroscopy and Radiative Transfer, 205:278–290, 2018.

Contact

For any question or further information regarding the present work, please contact the authors at the following email addresses:

Alexandre Simoneau: alexandre.simoneau@usherbrooke.ca

Martin Aubé: martin.aube@cegepsherbrooke.qc.ca