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Light-pollution measurement with the Wide-field all-sky image analyzing monitoring system

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Abstract. The purpose of this experiment was to measure light pollution in the capital of Czech Republic, Prague. As a measuring instrument is used calibrated consumer level digital single reflex camera with IR cut filter, therefore, the paper reports results of measuring and monitoring of the light pollution in the wavelength range of 390 - 700 nm, which most affects visual range astronomy. Combining frames of different exposure times made with a digital camera coupled with fish-eye lens allow to create high dynamic range images, contain meaningful values, so such a system can provide absolute values of the sky brightness.
Key words: light pollution – DSLR – HDR imaging – all-sky monitoring

1. Introduction

Light pollution is a kind of environmental degradation, strongly affecting natural light sources. Scattering of the artificial light in the atmosphere reduces the contrast of the night sky, thus making almost impossible to observe faint objects. The amount of pollution depends on the spectral characteristics of the artificial light sources, with the more environmentally friendly sources being low-pressure sodium, followed by high-pressure sodium. Most polluting are the sources with a strong blue emission, like metal halide and white LEDs, which are increasing light pollution of more than five times the present levels (Falchi et al., 2011).

Naturally, there is a big effort to measure and quantify the impact of the light pollution. Long-term studies use satellite image data (Bennie et al., 2014; Dziurdzikowski et al., 2014) or data from ground-based measurements, employing mostly special devices like Sky Quality Meter[1] (SQM), spectroradiometers or sensitive wide-angles CCD or CMOS cameras (Tohsing et al., 2013; Rabaza et al., 2014). Another popular technique is a systematic measurement of the sky radiation by the use of a telescope mount equipped with the CCD camera. Thanks to the work of citizen scientists exist initiatives like smart-phone based spectrometers (Dupuy & Knox, 2014). Data acquired from the calibrated devices are then used to calculate the apparent brightness of the sky background,

[1] http://www.unihedron.com/projects/darksky/

measured in magnitudes per square arcsecond (mag/arcsec^2), a unit widely used in astronomy to quantify brightness. A deeper analysis of the problem including numerical models of the emission function can be found in (Lamphar & Kocifaj, 2016).

The paper is organized as follows. Section 2 introduced camera system used for measurement. Section 3 describes process of camera calibration. Section 4 shows results and finally Section 5 concludes the paper.

2. Wide-field all-sky image analyzing monitoring system

The wide-field all-sky image analyzing monitoring system[2] (WILLIAM) is an experimental camera with Ethernet connectivity, employs DSLR, ultra wide-field lens and small router as a main components (Janout et al., 2015). Camera Nikon D5100 with a 23.6×15.6 mm CMOS sensor offering 4928×3264 pixels resolution is used. A life cycle of a camera shutter is expected to be 100k cycles, which might provide a three-year service, assuming 8 hours of observation per night. The camera is equipped with a fish-eye lens Sigma 10 mm f/2.8 that was chosen for its full frame (diagonal) lens. The camera is set up such that the sky coverage is slightly less than all-sky, because it has a 180° diagonal view angle.

The camera is connected via USB port to the Raspberry Pi computer, running a GNU/Linux operating system Raspbian[3]. The camera system as a whole is controlled by a master script from the computer, which also provides a control of the camera system (setting a gain, time, shutter, etc. by the use of gPhoto2[4] library) and handles post-processing scripts in a remote PC.

3. Camera calibration

There are various approaches published on camera characterization (Fliegel & Havlin, 2009) and analyzing the usability of commercial digital cameras for scientic purposes, including light pollution measurement (Zotti, 2007).

For the purpose of this experiment, the calibration was done using ISO camera OECF test chart which consists of a diffuse reflective surface with 12 gray scale patches stepped in visual density increments. The test chart was illuminated with large area light sources to obtain the highly uniform distribution of illuminance. The camera was placed at a distance of about 1.2 m from the test chart, and the raw image data was captured. At the same time, the luminance meter was used to evaluate the actual luminance of the 12 patches.

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[2]Project website: http://william.multimediatech.cz/
[3]OS website: https://www.raspbian.org/
[4]Library website: http://gphoto.sourceforge.net/

4. Results

Once calibrated, DSLR could be employed as a luminance meter. Left part of the Figure 1 displays calibration curves for different EV (i.e. the combination of aperture and exposure time). This calibration curve allows calculating luminance of the scene. However, the light pollution measurements are presented in a variety of ways and units – this fact makes comparison of the studies difficult. Thus, in this paper is used formula published in Garstang (1986), quotes the relation between sky luminance b in cd/m^2 and the unit of mag/arcsec^2

$$b[mag/arcsec^2] = 12.603 - 2.5log_{10}b[cd/m^2] \quad (1)$$

WILLIAM is acquiring frames during the whole night on regular basis, with the time interval of 10 minutes. Right part of the Figure 2 displays example of sky luminance in zenith measured in two different places of Czech Republic – Prague and Jarošov, small village in south Bohemia. Figure 2 then shows luminance map of both places at the almost the same time. Image sequences were acquired during the night of June 6, 2015. Weather conditions were similar on both places, Prague was a bit cloudy. While the faintest object detected by WILLIAM in Prague had the magnitude of 12.7020, the faintest object detected in Jarosov at the same time had the magnitude of 13.3342.

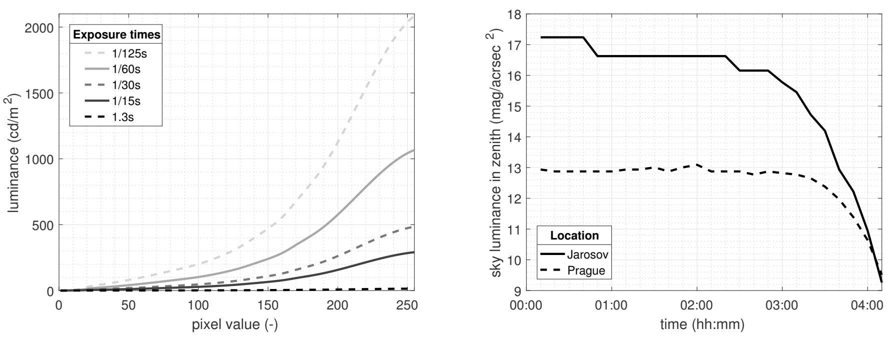

Figure 1. Left: relation between radiance and pixel value, aperture f/5.6. Right: measured sky luminance in zenith between midnight and sunrise.

5. Conclusions

In this paper, the brief description on how to roughly measure light pollution with wide-field camera system was given. The results show measurements at two different locations in the Czech Republic, in the capitol city and the village

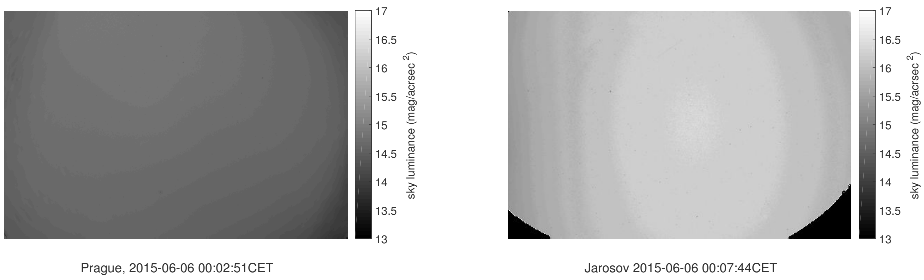

Figure 2. Luminance map of the night sky, measured on both WILLIAM stations.

with little influence of artificial sources of light. Obviously, the conditions for astronomical observation in the city are poor. Further work includes providing the statistics of light pollution on a daily basis.

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