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Instrumentation for long term measuring of parameters under night sky

Abstract. *The paper deals with equipment for long-term measurement. We want to collect information about night sky, quantify the obtrusive light and compare the level of it in industrial and habited areas and out of them. For long-term measurements of low level illuminance (about 10-3 lx) and luminance (about 10-3 cd/m2) should be applied not only the measuring equipments with high sensitivity, but also completely independent one with the ability to save the measured data.*

Streszczenie. *Artykuł mówi o przyrządach do pomiarów długoterminowych. Chcemy zebrać informacje o nocnym niebie, określić ilościowo zanieczyszczenie świetlne, porównać jego poziom na obszarze przemysłowym i zamieszkałym a także poza nim. Do długoterminowych pomiarów niskich poziomów natężenia oświetlenia (ok. 10-2 lx) i luminacji (ok. 10-3 cd/m2) koniecznym jest użycie urządzeń nie tylko o wysokiej czułości, ale także z całkowicie niezależną możliwością zapisu namierzonych danych.* ***(Instrumentarium długoterminowych pomiarów parametrów nieba nocnego).***

Keywords: camera, obtrusive light, luxmeter, luminance analyzer, sky quality meter, illuminance, luminance, magnitude.
Słowa kluczowe: kamera, zanieczyszczenie świetlne, fotometr, analizator luminacji, sky quality meter, natężenie oświetlenia, luminacja, magnitude.

Introduction

The main aim of this article is to introduce the possibility of luminance measuring by adjusted astronomical CCD camera cooled by Peltier cells. We selected a type of CCD camera which uses a monochrome cooled square chip with high-resolution and 16-bit A/D converter. It provides high sensitivity and wide dynamic range. Another important factor is that the camera is able to cooperate with the software (LumiDISP) for luminance evaluation from pictures taken by calibrated digital cameras. Taken pictures are immediately evaluated and transformed to luminance maps and stored in the preset database. In this way it is possible to set up long-term measurement, or control this measurement in distance measurement (the ability to communicate via internet).

The article also describes other measuring devices that are suitable for long-term evaluation of the state of obtrusive light at night (luxmeter, luminance analyzer, sky quality meter).

Description of the CCD camera G2-4000 used as a highly sensitive luminance analyzer

The camera is used for measuring the low levels of luminance for several reasons. The first reason is its high sensitivity, which is achieved by cooled CCD chip. The second very important reason is the possibility of inserting different optical filters in front of the black and white CCD sensor. It allows the optical adaptation to the human eye sensitivity for photopic vision, as well as we can measure mesopic and scotopic vision (while using other filters). The third reason is the possibility of exchanging the objective lenses and especially the using fisheye for whole upper hemisphere measuring. The last reason for using this type of sensor is the possibility of automatic operating and data storage to evaluating software. For the measurement of luminance is needed to connect the camera to the computer and use it together with optical equipment (objective lenses and filters).

For the night sky luminance measurements, the camera is equipped by a bayonet lens for Canon and disc for 5 filters per 1.25-inch holders.

Currently is for luminance evaluation used filter with characteristics for V_λ curve adaptation. In the near future we are thinking about the usage of filters, which in combination with a quantum efficiency curve of the CCD sensor dependent on the wavelength sensitivity of the measuring device adapted not only for sensitivity of the human eye for photopic vision $V_{\lambda,}$, but also for scotopic vision $V'_{\lambda,}$ and mezopic vision.

Fig. 1. CCD camera equipped with fisheye lens and placed on a tripod to capture the upper hemisphere luminance

CCD Camera Parameters:

Model G2-4000 uses a 4-megapixel CCD square chip Kodak KAI – 4022. Chip resolution is 2056 x 2062 pixels. Size of one pixel is 7,4 x 7,4 μm and image area is 15,2 x 15,2 mm. The full capacity of the pixel is approximately 40 000 electrons and full capacity output data is approximately 100 000 electrons. The manufacturer specifies dark current 0,3 e-/s/pixel at 0° C. The dark current doubling occurs at 7° C.

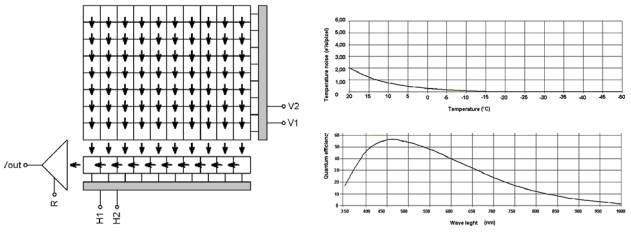

Fig. 2. Schema of CCD chip used for the CCD camera (left), its dark current (upper right) and quantum efficiency (bottom right)

After calibration of CCD camera can be expected range of the measured luminance from 10^{-4} cd/m^2. Maximum measured value of luminance is limited by shutter speed.

Temperature of the CCD is regulated with accuracy ± 0.1 ° C. Cooling minimizes dark current of CCD chip very effectively and precise temperature regulation allows proper

calibration. Camera head contains two thermal sensors - the first directly measured temperature of the CCD chip, the second sensor measured the temperature of the hot side of Peltier cells.

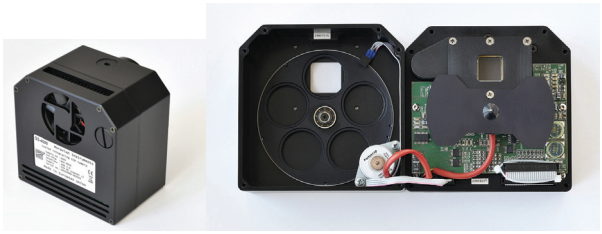

Fig. 3. Ventilator location for cooling Peltier cells and interior of CCD camera with disc for 5 filters

The comparison of the measurement CCD camera and luminance analyzer LMK Advanced Mobile

CCD camera have 16-bit A/D converter with a correlated double sampling. This converter provides high dynamic range and read noise at the CCD chip level itself. Brightness range of one picture enables the resolution up to 65535 levels, while the luminance analyzer with 12-bit A/D converter allows a resolution only 4096 levels.

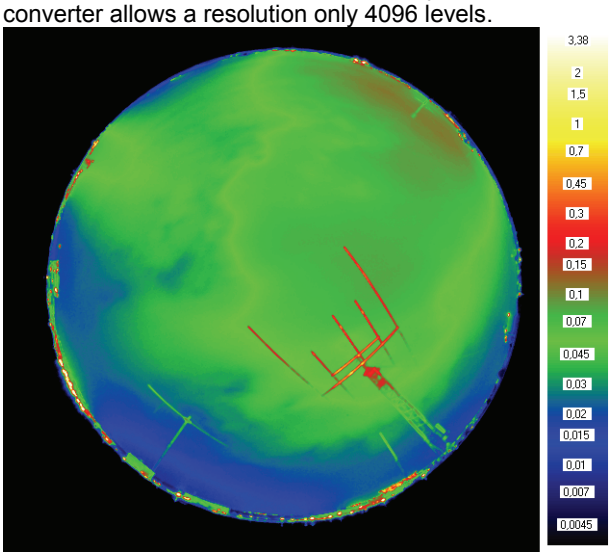

Fig. 4. Example of night sky luminance measurement by luminance analyzer LMK Mobile Advanced and with Fisheye lens

To compare the evaluation of pictures taken by a CCD camera are shown pictures taken by luminance analyzer LMK Mobile Advanced with Fisheye lens. In Fig. 4 we can see the luminance values assigned to individual colours. Luminance maps made with the program LMK 2000 are taken by numerical calculation from 4 colour pixels (R, G, B, G) which adapt photo to sensitivity of the human eye. These pictures have a resolution about 1730 x 1150 pixels. The pictures taken by the CCD camera are transformed to human eye sensitivity by optical filters (the filter can be changed and then realized the measurements in the field of scotopic and mezopic vision). The chip of CCD camera has a square form and its resolution is 2056 x 2062 pixels. It is better to use it with fisheye objective. The dynamic range of the both devices can be increased by combining the pictures which have different exposure time.

In Fig. 5 is shown night sky taken by CCD camera with fisheye lens in the programme SIMS. CCD camera communicates with the computer directly and individual pictures can be modified in other special software. In the picture with histogram is clear that the whole dynamic range is without saturation on the chip, and it wasn't necessary to take a new picture with a different exposure time. If we look properly at luminance maps taken by luminance analyzer LMK Mobile Advanced (see Fig. 4) we can find that too bright points near the horizon are already in saturation and therefore it is not possible to identify their luminance. Below the taken picture (see Fig. 5) there is shown a colour palette histogram that assigns values to each pixel. We can see (see Fig. 5) that the values of the excitation of most pixels in the picture are in the first fifth of the possible excitation.

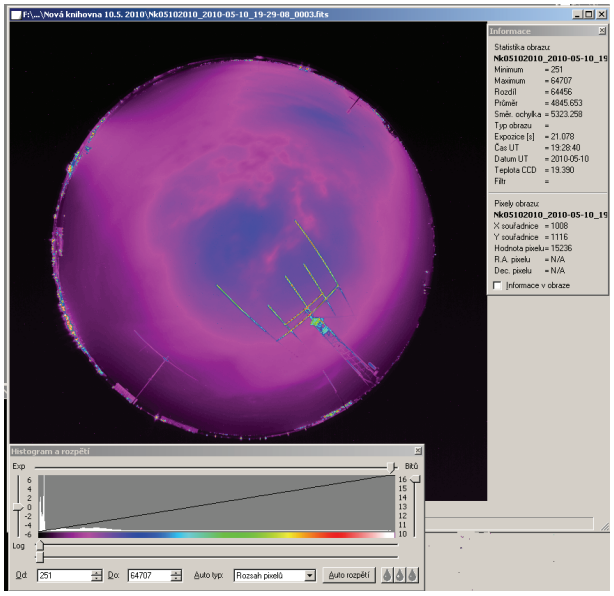

Fig. 5. Measurement of the night sky brightness using CCD camera with a Fisheye Lens

In picture (Fig. 6) there is visible the window from programme LumiDISP with imported three identical test pictures with different exposure taken by the CCD camera. By the combination of three luminance channels from Fig. 6 can be obtained one luminance map of the situation so that it is possible to see lowest and highest luminance together. Programme LumiDISP also allows the values checking of individual pixels, evaluating the average values of specific areas, etc.

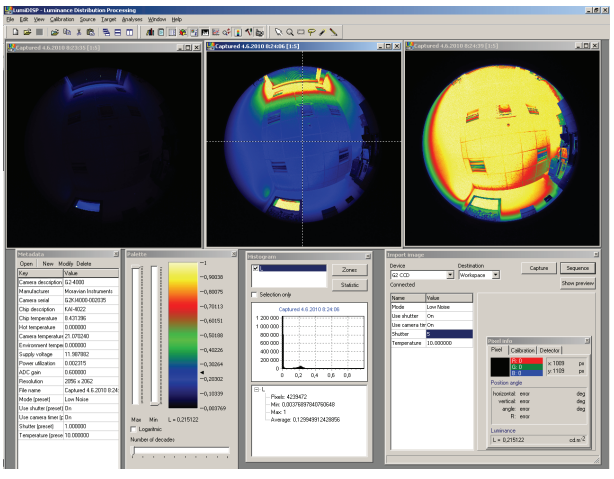

Fig. 6. Example of pictures evaluating by LumiDISP programme

To connect the CCD camera to the computer is fast USB interface, which allows image downloading within a few seconds (about 8 s). Maximum length of USB cable is 5 m. This length can be extended to 100 m using a USB hub or an active USB extension cable. Then the camera can be

placed on a higher measuring point under cover and leave the computer in the room where his work will influence the weather conditions.

Station for long-term measuring of the night sky luminance is installed to the existing measuring instruments on the Nová Knihovna building of the Technical University of Ostrava.

Digital luxmeter for long-term measurement of illuminance

To measure of illuminance is needed quality photovoltaic sensor be able to convert a wide range of illuminance to current. In the design concept of this device was taken account the requirements for a wide measuring range (from 10^{-3} lux to 10^{5} lux), the possibility of zero calibration, the possibility of long-term operation without operator, charging from the battery and from the electric distribution, automatic range switching, the possibility of sending the measured data into a computer, the possibility of saving measured data to internal memory and later downloading to computer.

With today's electronic equipment level, each of these requirements are achievable quite easily, but all together it is difficult task. A key problem is the measurement of small levels of illuminance.

Base for luxmeter with high sensitivity (the ability to evaluate illuminance about 10^{-3} lx) is a high quality sensor adapted to sensitivity of the human eye curve. If the sensor is not good enough, you can not evaluate objectively illuminance by the best electronic circuits.

For linear transfer of illuminance to the electrical units from very small illuminance values it is evaluated current and it is preferred in short state. This can be realized by current-voltage converter with an operational amplifier. Currents, which the converter operates with at the illuminance up to 1 lx are very small (approximately – nA). Operational amplifier for these currents must be able to evaluate very small input, preferably by several degree orders smaller than the operating current. These requirements meet the operational amplifiers with FET input. At the same time it needs to have a minimum noise and drift and it must be able to work with low supply voltage (the requirement for a battery). It was chosen operational amplifier AD822. To reduce the noise (to provide sufficient accuracy) an analogue part of the photometer is shielded.

Description of luminance analyzer LMK Mobile Advanced

To measure the luminance it is used digital reflex camera Canon EOS 350D, which records the real scene in digital form on a storage medium by the CMOS sensor. This camera can change different lenses so that the image evaluates the situation as the most authentic. This device is necessary to operate manually throughout the measurement. For this reason, it fits for short-term night sky luminance measurement only.

For the processing of the measured images from LMK mobile advanced must be used software LMK 2000. Evaluation is based on the data used in CR2 format, where the image is recorded in the RAW form. This form contains the "raw data", which means that the recorded information is stored in its original form, without any additional correction as it is in other formats (JPEG, BMP, etc.).

The software can extend the range of luminance analyzer and set the level of exposure to + / -2, so the scene is recorded to three separated places with the exposure levels -2.00 EV, 0.00 EV and 2.00 EV.

From the measured pictures (three composite exposures) it is computed a luminance channel. This channel stores information about the value of luminance for each macro-pixel. Macro-pixel contains 4 pixels (R - red, G1 – green 1, B - blue, G2 – green 2), where is stored the values recorded by CMOS sensor of camera. Adaptation of the camera relative spectral sensitivity to the human eye sensitivity ($V\lambda$) is performed by numerical matrix. Information stored in the luminance channel can be processed and evaluated further.

The measuring instrument operating is simple and it can be used for the terrain survey of luminance.

Analyzer is used to measure luminance ratios on roads, pedestrian crossings, sidewalks, tunnels, indoor surfaces, etc. Moreover it can be used for obtrusive light measurement.

Instrument SQM-LE

The last described device for long-term measuring of the night sky is astronomical instrument (Sky quality meter), which evaluates the luminance of the night sky. This instrument does not work with lighting units (cd/m2), but in magnitudes (mag). For traditional reasons, astronomers use the term magnitude, expressed in units called magnitudes. Magnitude is a logarithmic value. This instrument is able to compare the astronomical measurements and lighting ones.

SQM (Sky Quality Meter) is a device for measuring the brightness of the night sky in the visible spectrum in astronomical units. Measurements display the results in mag/arcsec^2 units. The results can be converted to the luminance (cd/m^2) according to the following formula:

$$L = 10{,}8 \cdot 10^{4} \cdot 10^{(-0{,}4 \cdot mags)} \text{ (cd/m}^2\text{;mag/arcsec}^2\text{)} \quad (1)$$

where: L –corrected luminance, mags – measured value with SQM-LE

Long-term measurements by the SQM-LE device using the SQM reader software is performed by time intervals settings for data recording. This measurement setting may take place throughout the whole night and record the brightness values (mag/arcsec^2). Measured values can be converted to luminance values according to formula (1).

Conclusion

Using the above mentioned measuring devices and their accessories can be measured and evaluated different parameters of the night sky. The measured data can be converted to relative values and compare the results from different types of devices which can measure in different areas and during changeable weather conditions.

Suitable devices placing make it possible to observe the effect of measured light source (e.g., city) from several points and determine the level of the obtrusive effect of it.

Acknowledgement

This article has been supported by common project KONTAKT 2010 with Czech and Slovak Republic, named "Overgrand light source, luminance, and night sky radiation: spectral and integral curves".

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