Measuring Light Pollution with Camera

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***Abstract*—Light pollution, which has been defined as the disturbance of the nocturnal environment, has been a growing problem lately. This work describes an idea for measuring light pollution using a four channel (RGB + IR) camera and an algorithm. The algorithm classifies high-intensity discharge lamps and solid-state lamps. Its final goal is to estimate the fraction of LED lights in light pollution.**

***Index Terms*—Light pollution, spectral resolution, four channel camera**

I. Introduction

Most of the world's population lives in cities and urban areas where night lighting is a necessary condition of housing. Artificial lighting in cities is increasingly overpowering natural darkness. Light pollution directly affects the ecosystem and threatens its normal course of life, but also affects a person's normal rhythm of life, causing sleep deprivation, depression and disturbance of the circadian clock, [1], [2]. Furthermore, light pollution, due to the highly illuminated night sky, also affects the research and work carried out by astronomers and physicists, [3]. Finally, a lot of energy is wasted that could have been conserved or used for other purposes.

Light pollution may occur in the forms of glare, light trespass, skyglow and over illumination, [4]. When speaking about the glare, in many cases, the problem is not so much the kind of light source or its brightness as the construction of the cover or inclination of the shield to the plane of the horizon. Older models of street lamps with a convex cover of the light source which, in addition to illuminating a dedicated object (road, pavement, parking), also send a large part of the luminous flux above the horizon, [1]. The light sources used in the public lighting are high-pressure discharge lamps such as the High-pressure sodium lamp and the solid-state light sources. Lately, the number of solid-state light sources as the LED light bulbs has been increasing despite the fact that the high spectral density of blue light emitted from them affects human's health.

Light pollution is being researched and there are numerous studies that have been done from the ground, [5] but it is our idea to try to measure light pollution using the student FERSAT satellite. The idea behind the measurement is to take images of the Earth at night and try to determine the type of light source. Also, the final step is to estimate the fraction of LED light bulbs in light pollution. These measurements would be carried out with a four channel camera — a standard red, green, blue and an added infrared channel that would allow us to distinguish the light bulbs from the light mixture.

II. Geolux camera

In our research we used Geolux RSS RGB+MWIR Camera to capture the images. Geolux is a Zagreb-based company that specializes in industrial cameras. Their RSS RGB+MWIR Camera uses AR0238 CMOS detector, has four channels, and its spectral range is from 395 nm to 900 nm. The resolution of the camera is 2.1 Megapixels and despite having small electronics dimensions, its embedded processor power is very high.

The data format used in our approach is raw image sensor data, which, unlike JPEG and other standard formats, contains data that has minimal processing applied and preserves most of the obtained information. Each data file can be represented with a two-dimensional array consisting of 1920 pixels horizontally and 1080 vertically, with no metadata included.

The value of each pixel is proportional to the amount of detected current from the camera's sensors. It is stored in 16 bits of data, out of which the first four are set to zero, resulting in 12 bit pixel data. Different coloured pixels are distributed evenly over the ccd, following a regular pattern of G, R, G, B in the odd number rows, and IR, G, IR, G in the even number rows.

We introduced the composite pixel, a part of the image that represents a minimal package of data containing complete information (all four channel values), which can be seen on Fig.Raw data array with composite pixel. It is consisting of 8 pixels (4 G, 1R, 1 B, 2 IR). Since there are multiple G and IR pixels in the composite pixel, mean values are taken as representative. For the further development and the idea of the algorithm, we will use the composite pixel.

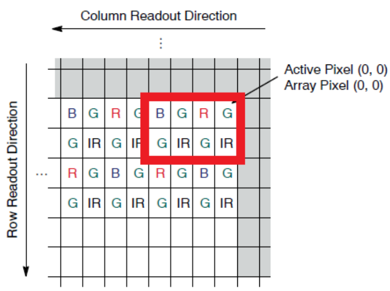

Fig. 1. Raw data array with composite pixel. Composite pixel is regulary repeated in the array. There are over 259 000 composite pixels in a single data array, [7].

III. The measurements

In order to develop algorithm for the classification of light source type based on a photograph, we had to collect a set of as many light sources. Light sources that are relevant for our research are the ones that are most commonly used for the public lighting. We took photographs of lighting from 10 different light sources whose characteristics are listed in TABLE Light sources' characteristics while the light sources themselves are shown on the Fig.Light sources.

TABLE I
Light sources characterized (all E27 base)

Code	Description	Power	CCT
HG	Mercury vapor	125 W	
HPS	High-pressure sodium	70 W	
MH3	Metal-halide	150 W	3000 K
MH4	Metal-halide	150 W	4000 K
HAL	Halogen	70 W	2800 K
CFL	900 lm, CRI>80	15 W	2700 K
LED6	806 lm, CRI>80	9 W	6500 K
LED4	806 lm, CRI>80	9 W	4000 K
LED3	806 lm, CRI>80	9 W	3000 K
LED0	1000 lm, CRI 90	11 W	2700 K

Fig. 2. Light sources used for measurements (from left to right): HG, HPS, MH3, MH4, HAL, CFL, LED6, LED4, LED3, LED0

The problem that we encountered while acquiring data set were saturated areas of the picture. Each composite pixel having at least one of the pixels that it is comprised of saturated (having maximum value, in case of 12 bit format 4095), is considered saturated. Since these areas of the pictures containing saturated pixels are not useful for processing, we had to reduce the number of the saturated pixels.

In the measurements, the light sources were put under the diffuser and the lens on the camera was defocused. With these measurement adjustments, we spread energy from the light sources to as many pixels as possible so the detected value of pixels would not be as high as it was before the adjustments.To eliminate any remaining saturated pixels, we checked the values of composite pixels and removed them from the data set. Also, each light source was photographed at three different levels of lens f-stop, which is the ratio of the system's focal length to the diameter of the entrance pupil, because we wanted to test different conditions for the algorithm.

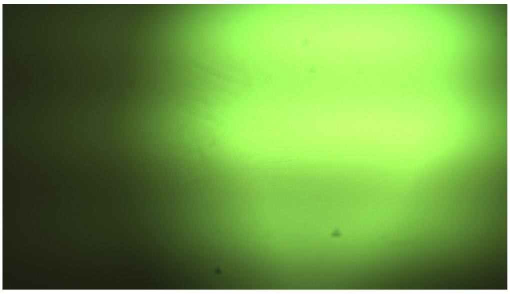

Fig. 3. Mercury light bulb under the diffuser and with defocused camera lens. Images that were taken for the research looked like this.

IV. The algorithm

A. The background

The main hypothesis of our research is that data obtained with our four channel camera is enough to differentiate between different light sources. The first step of the algorithm is to find the area in the picture with the maximum intensity without the saturation. After finding the maximum intensity pixel, we extracted the area around that composite pixel. We took the area of nearby 300 composite pixels and averaged their values of each of the four components, resulting with four values: R_{Avg}, G_{Avg}, B_{Avg} and IR_{Avg}, for each photo.

Then, we calculated S, representing the average of the total amount of red, green and blue component in the image.

$$S = R_{Avg} + G_{Avg} + B_{Avg}$$

Finally, we introduced variables X, Y, Z, that stand for

$$X = \left(\frac{R_{Avg}}{S}\right),$$

$$Y = \left(\frac{G_{Avg}}{S}\right),$$

$$Z = \left(\frac{B_{Avg}}{S}\right)$$

and are commonly known as chromaticity coordinates. Now $X + Y + Z = 1$, and from this expression we can see that only two out of these three values are required to specify any colour. The third one can easily be calculated from the known ones.The data of the each photo can then be shown by a single dot in a two-dimensional graph. Respecting CIE 1931 xy chromaticity diagram representation, we placed percentage of red component(X) on x axes, and percentage of green component(Y) on y axes. The results of plotting 3 images for each of the 10 light bulbs are shown in Fig.Results of the algorithm.

B. The results

Some results we hoped to achieve are visible straight from the graph, and those are groupations formed by dots representing the same light bulb. This is the main assumption our research lies on and is the base of future algorithm for distinguishing different light sources.

What we expected was that, because of linearity of the sensor, all 3 measurements for the same light bulb would hit into the same dot, but we got small errors. These errors, however, can easily be attributed to aperture inaccuracies [6] caused by changing the f-stop value, and possible noise during measuring process. Furthermore, we can see that we have good distinguishment between a group of Mercury lamps and other lamps in the graph. The main reason why this happens is because Mercury lamps emit light with greenish tint, so their y component (percentage of green) is higher than the average.

When it comes to LED lamps,it is interesting to notice that their linear placement, and the order of their CCT (Correlated Color Temperature) values from highest to lowest, resembles black body curve of the earlier mentioned CIE chromaticity diagram in the white area of the gamut which can be seen on the Fig.Gamut.

V. Conclusion

Monitoring total light pollution from space has been active since the 1970-ies. Performing

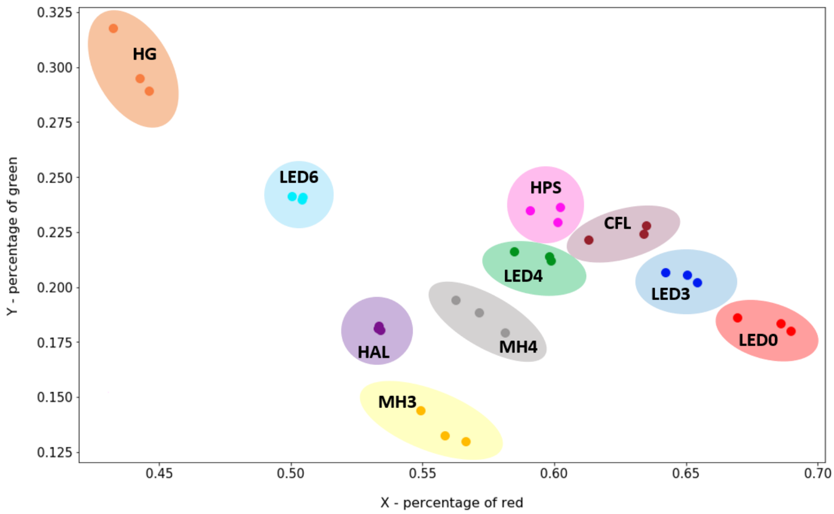

Fig. 4. Results of the algorithm. Light sources and their pared colors on the graph: (HG, orange), (HPS, pink), (MH3, yellow), (MH4, gray), (HAL, purple), (CFL, brown), (LED6, cyan), (LED4, green), (LED3, blue), (LED0, red)

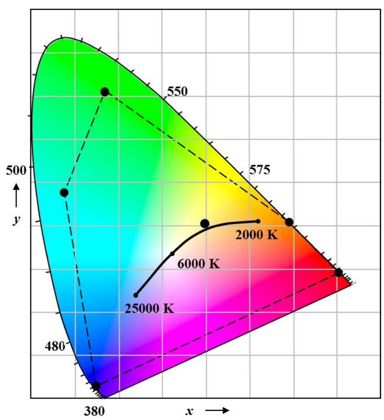

Fig. 5. Gamut. The black body curve in the area of the white light goes from warmer colors that have lower CCT to colder colors with higher CCT.

spectrally resolved night-time imaging of Earth is potentially a good approach to quantify the progress of solid-state lighting and light pollution on a global or local areas. In this work we have shown the idea of measuring the light pollution by classification of the light sources using a four channel camera and algorithms. The idea gives promising results, but a lot of problems and questions stil need to be answered.

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[7] AR0238: 1/2.7-Inch 2.1 Mp/Full HD Digital Image Sensor