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Illumination Detection for LED Dimming Process Efficiency Evaluation

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***Abstract*—Light sources as LEDs are with high efficacy and have possibility of light dimming. A microprocessor controlled photo sensor array enables automatic measurement process of obtaining photometrical and electrical parameters, for preliminary testing of developed luminaries, existing products and analyzing data to evaluate lighting dimming process efficiency at different dimming levels.**

***Index Terms*—Current control, electrical ballasts, LED lamps, lighting control.**

I. Introduction

The demand for new energy efficient lighting solutions in lighting industry is growing, as it is stimulated by continuous development of artificial light sources based on light-emitting diodes (LED).

Already many LED light source based street lighting luminaries with various electrical and optical performance parameters are available on global market, still just few of them can be used in more efficient way, as the main feature of LED light source is possibility to control luminary light output in full range (dimming), thus making system more energy saving [1], [2].

It is difficult to estimate luminous efficiency of artificial light source (whole fixture) only by assessment of efficiency of power supply. During development of power supply unit for new LED luminary also it is necessary to get preliminary photometric readings to evaluate lighting dimming process efficiency at different dimming levels, as the LED current, junction temperature, lifetime, light output, efficiency, can influence each other.

II. Concept of Luminary Evaluation Stand

Fig. 1 describes concept of luminary evaluation stand. The idea of illumination measurement system is to estimate light distribution of artificial light source in particular direction. The system consists of matrix of illumination measurement elements (sensors) and spectral power distribution values of the measured light are obtained from spectrometer (Fig. 1).

Gathered data from sensors is recalculated, using spectral power distribution of the measured light. Implementation of spectrometer is supposed to help reduce price of needed high precision photo detectors (especially in system with large amount of photo detectors), and save on expensive V(λ)-correction filters. Precision of proposed method and calculations must be evaluated and compared with results obtained from calibrated devices.

In the same time with light source optical parameters it is planned to take measurements of electrical parameters of light source power supply.

Measured data from photometer matrix and spectrometer is collected and processed in main data collection unit - computer with special software. Software recalculates sensor measured data according to light spectral power distribution.

Illumination measurement stand consists of metal frame and light source fixture. At the bottom of the illumination measurement stand a matrix of 25 sensors is placed. To avoid measurement interference with ambient light, the stand is tapestried with thick black textile with low reflection properties.

III. Influence of Spectral Distribution of Light on the Measurements

Main “consumers” of light are human eyes, so sensitivity of eye should be taken into account in light measurements. International Commission on Illumination (CIE) in 1931 has introduced human eye sensitivity function $V(\lambda)$, which was modified in 1978 (Fig. 2). According to CIE resolution of year 1990 it is preferable to use CIE 1978 $V(\lambda)$ function for measurements in range of short wavelengths (white LED combines a blue LED light which is in range of short wavelengths, and yellow-green phosphor radiation).

Value of the luminous flux can be found knowing the radiometric radiation power of light source

$$\Phi_v = 683 \int_{360nm}^{825nm} V(\lambda) \cdot P(\lambda) \mathrm{d}\lambda, \quad (1)$$

where $P(\lambda)$ is power of optical radiation for corresponding wavelength in watts [3].

Described above system uses low cost ambient light sensors (with two measurement channels - photodiodes) provided for portable devices (APDS-9300). Spectral response of such a sensor is completely different from human vision (Fig. 3). To get precise illumination measurements, correction of sensor sensitivity or recalculation of obtained data need to be done, but the price

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on the $V(\lambda)$-correction filters is rather high.

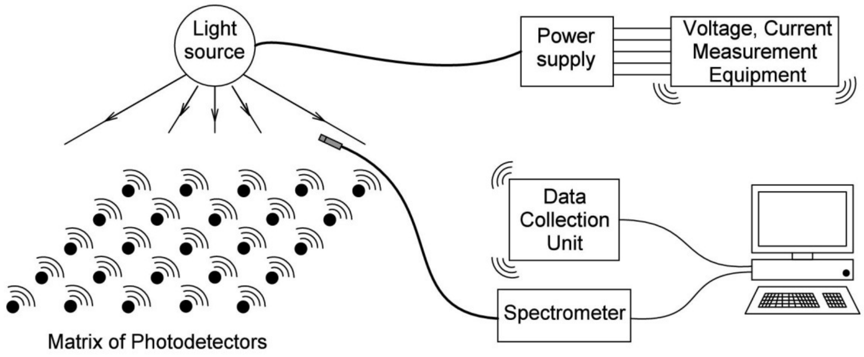

Fig. 1. Concepts of luminary evaluation stand.

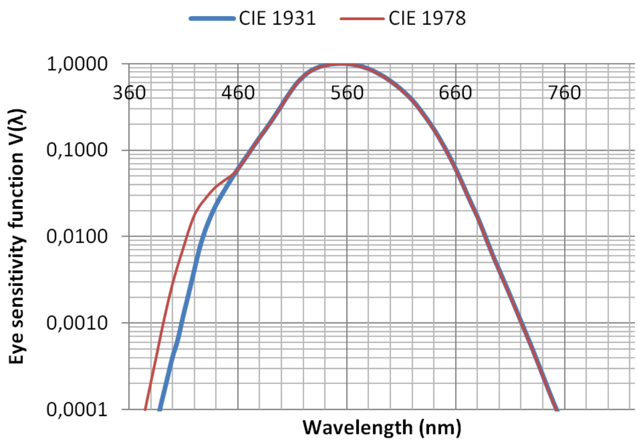

Fig. 2. CIE human eye sensitivity function $V(\lambda)$.

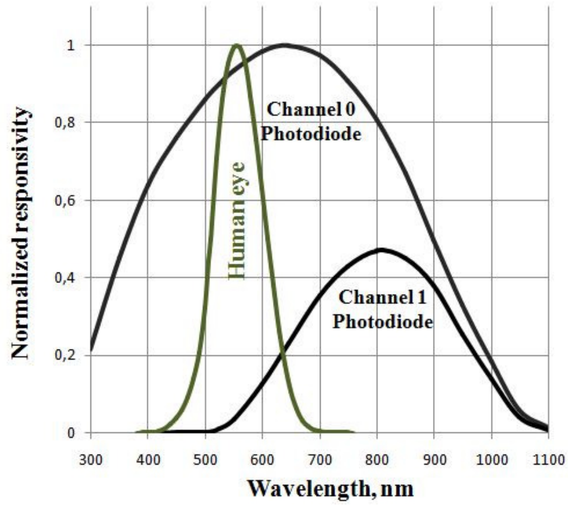

Fig. 3. Sensitivity of the photo sensor and human eye.

Reference [4] describes principles of recalculation of photometer measured value in amperes into illuminance value in lux, using typical photometer, consisting of a silicon photodiode, a $V(\lambda)$-correction filter, and a precision aperture. First, the absolute spectral sensitivity $s(\lambda)$ (in A/W) of the photometer is determined based on the absolute spectral sensitivity scale. The area of the aperture A is measured by using a dimension measuring instrument. Sensitivity s_v (A/lx) of the photometer is then obtained by

$$s_v = \frac{A \cdot \int S(\lambda) \cdot s(\lambda) d\lambda}{K_m \cdot \int S(\lambda) \cdot V(\lambda) d(\lambda)}, \quad (2)$$

where $S(\lambda)$ is the spectral power distribution of the light to be measured, Planckian radiation at 2856 K is normally used for $S(\lambda)$. The calibrated photometer provides the unit of illuminance [5].

Light sensor provides measured photodiode current in ADC counts, so recalculation equation must provide count/lx units, taking in account human eye characteristics. (1) is base for recalculation.

Spectral power distribution of the light source $S(\lambda)$ and absolute spectral sensitivity of the photometer $s(\lambda)$ can be written in relative units (normalized values)

$$S`(\lambda) = \frac{S(\lambda)}{S_m}, \; s`(\lambda) = \frac{s(\lambda)}{s_m}, \quad (3)$$

where S_m (in W/nm) is maximum spectral power of the measured light, s_m (in counts/W for digital sensor) is maximal count value of photometer absolute spectral sensitivity. Then (2) can be written as

$$s_v = \frac{A \cdot S_m \cdot s_m \cdot \int S`(\lambda) \cdot s`(\lambda) d\lambda}{S_m \cdot K_m \cdot \int S`(\lambda) \cdot V(\lambda) d(\lambda)}. \quad (4)$$

(4) can be divided into two parts: constant coefficient ($A \cdot s_m/Km$) that depends on aperture of photometer, and variable part that depends on measured light spectral power distribution. Variable part remains constant for one light source type, and is independent from intensity (i.e. distance from light source).

IV. ASSESSMENT OF LUMINOUS EFFICIENCY OF ARTIFICIAL LIGHT SOURCE

There are several parameters associated with luminous efficiency of light source.

Luminous efficiency of optical radiation ε_r is the coefficient, which is the ratio of radiant flux Φ_e to the luminous flux Φ_v of this radiation

$$\varepsilon_r = \frac{\Phi_v}{\Phi_e}. \quad (5)$$

Luminous efficiency of light source ε_s is the ratio of luminous flux Φ_v to the input electrical power

$$\varepsilon_S = \frac{\Phi_v}{P_{act}}, \quad (6)$$

where P_{act} is light source active electrical power.

The first one does not depend on the construction of luminary. This parameter characterizes only the source of light, however, secondary optics of LEDs or luminary optical system may affect this parameter if spectral distribution of light is changed (if optics absorbs light source radiation in some range of wavelength).

The last one is more usable for evaluation of luminary. It takes into account efficiency of whole fixture including efficiency of light source, efficiency of optical system of luminary and electrical equipment. Luminous efficiency of light source is important parameter for evaluation of LED luminary at different dimming levels.

V. Estimation of Electrical Power of Luminary

LEDs are low voltage DC consumers. They usually require electronic ballast. Depending on energy source (accumulator, battery, power grid etc) LED ballasts are DC-DC or AC-DC switching converters. Input current of switching converter is distorted by capacitance, inductance and discrete elements; input voltage and current are multi-component signals. For example input voltage and current waveforms of 36W LED lamp are shown in Fig. 4. Simultaneous measurements of instantaneous values of voltage and current are necessary for power calculation.

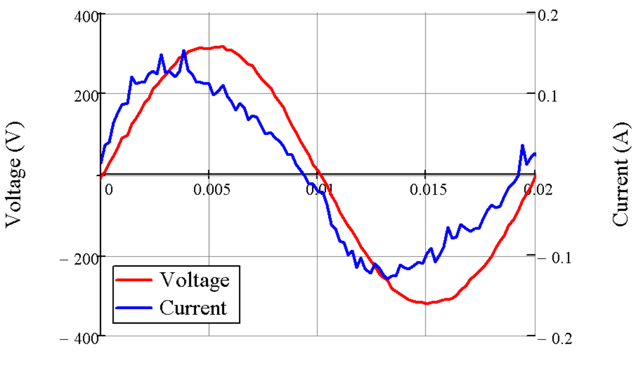

Fig. 4. 36W LED lamp input current and voltage forms.

Active power estimation for analog or digitized signals is based on the relation

$$P_{act} = \frac{1}{T}\int_0^T v(t)i(t)dt \cong \frac{1}{N}\sum_{n=0}^{N-1} v_n i_n, \quad (7)$$

where T is period of repetitive signal, $v(t)$ and $i(t)$ are continuous-time voltage and current, N is number of acquired samples, and v_n and i_n are sequences of voltage and current samples [5]. (7) is a correct estimation of active power for integer number of periods T of coherent signal. According to (7) active power of Fig. 4 signals is 18.6W.

In practice, the data acquisition usually is non-coherent and the leakage effect appears. The leakage contribution can be reduced by relative enlarging of the measurement time [6].

VI. Assessment of Luminous Flux of Luminary

To find total luminous flux of light source it is necessary calculate integral of irradiance $E_v(\lambda)$ on whole sphere area

$$\Phi_v = \int_A\int_\lambda E_v(\lambda)d\lambda dA, \quad (8)$$

where A is area.

LED luminaries are designed so that light propagates in particular direction. Then luminous flux for luminaries with directional radiation at planar surface according to (7) can be defined as

$$\Phi_v \approx \sum_{n=0}^{N} E_{v_n}\Delta A_n, \quad (9)$$

where E_{vn} is illuminance measured in point N, ΔA_n is area associated with measurement point N (Fig. 5).

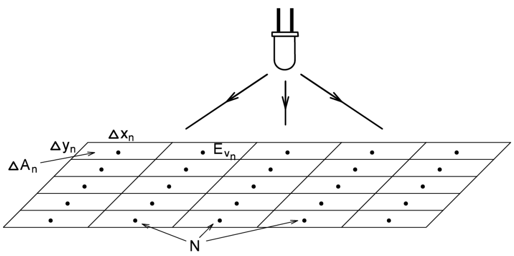

Fig. 5. Measurement grid with measurement points and associated areas.

Luminous efficiency in our case can be found using (6), (7) and (9). This approach is suitable for comparative estimation of one luminary at different dimming levels. Also it gives a preliminary picture of illuminance distribution of luminary. Estimation of efficiency of different luminaries may lead to erroneous assessment, because luminous flux is calculated using rather large area steps (0.25cm). However, better accuracy of luminous flux measurements can be achieved by increasing number of sensors.

VII. Results

Experimental measurements were held with array of 15 W7240C0 10W power LEDs. Here is a comparison of efficiency of two different dimming methods – PWM and fluent current regulation [7]. Electrical schematics for both of them are shown in Fig. 6 and Fig. 7.

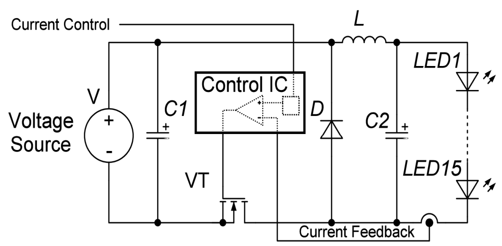

Fig. 6. Fluent current regulation dimmer; produced light amount is proportional to the current flowing through LEDs; operates as regulated current source.

Measurement conditions in both cases were similar: distance from LED array to sensor grid (height) h=0.5m, distance between sensors d=h=0.5m, 25 sensor grid, and 289 calculation points.

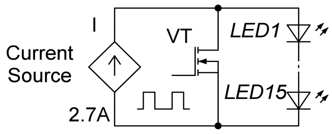

Fig. 7. PWM dimming technique; produced light amount is inversely proportional to the duty cycle of control signal.

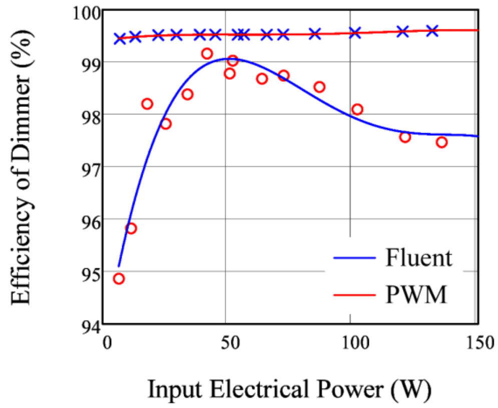

Fig. 8. Estimation of dimmer efficiency at different dimming levels.

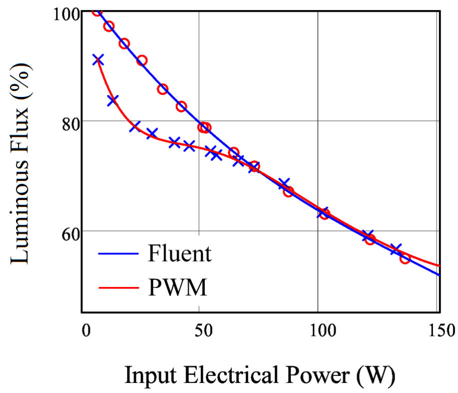

Fig. 9. Estimation of light source efficiency () at different dimming levels.

Fig. 8 and Fig. 9 show difference between dimming process estimation methods. Efficiency of dimmer on Fig. 8 is the ratio of output power to the input power in percents. Luminous efficacy on Fig. 9 is the ratio of luminous flux to the input electrical power. Maximal calculated value of luminous efficiency of experimental LED matrix is 106.9lm/W.

VIII. CONCLUSIONS

In this paper method of preliminary evaluation of luminary in development stage was described. A microprocessor controlled photo sensor array provides measurements of optical parameters of investigated luminary. Proposed system allows making a comparative assessment of the effectiveness of dimming process.

Using of ambient light sensor provided for portable devices in combination with spectrometer eliminates necessity of *V(λ)* correction filters, which reduces total costs of evaluation equipment.

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