LIGHTING SYSTEM FOR PATTERN RECOGNITION WORKBENCH BASED ON AN ARRAY OF TRICOLOR LEDS

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Abstract

Is well known, the way in which objects are illuminated is critical in a pattern recognition system. The goal of this work is to present a lighting system workbench specifically designed in order modify color and luminous flux allowing vision computer systems programmer verify the robustness of their algorithms. The work describes all methodology in order to control the LED chip determine luminous flux and chromaticity coordinate in the whole lamp. Detail of LED used and control implemented have been also included in the work. A experimental prototype has been built and tested.

Index Terms

Pattern recognition, tricolor leds, electronic driver,

I.- INTRODUCTION

The proposed lighting system described in this work has been optimized in order to work with a typical vision camera (PIXELINK PL-B742F). This camera is a color camera based on a CMOS sensor with a resolution of 1280x1024.

Figure 1 shows the spectral responsivity of the vision camera for each digital channel (red channel, blue channel and green channel).

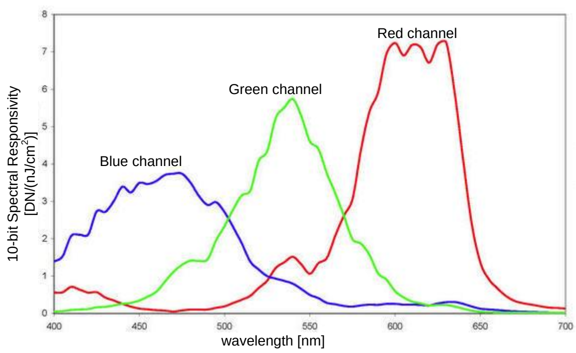

Fig. 1. Spectral responsivity of the vision camera

The blue channel shows its maximum responsivity value around 450 – 480 nm. The maximum in green channel is around 530-550 nm and finally in the red channel maximum values are obtained in the 590-640 nm.

II. LED SELECTION

Taking into account spectral responsivity of the vision camera and power LED technology available a RGB optical LED from OSRAM has been selected (reference LRTB-G6T6).

Fig. 2. Optical power LED LRTB-G6T6

This module has three chip LEDs inside the module (Red, Blue and Green LED) and it has been optimized for additive mixture of color stimuli by independent driving of each chip. The dominant wavelength of each chip LED is compatible with the maximum responsivity in the corresponding channel for the vision camera. Then, the maximum emission of the red chip is in 625 nm, the green chip are in 528 nm and the blue one is in 470 nm.

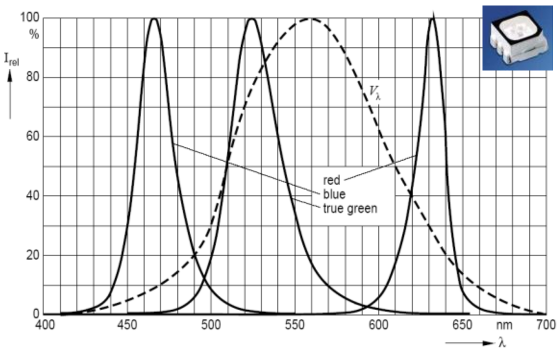

Fig. 3. Spectral emission of each LED chip

Chromaticity coordinates of each chip has been grouped during manufacturing process in order to avoid excessive color dispersion for each chip color LED. In this way, green chip LED has been chosen in the group 4. Figure shows the dispersion area of the green chip LED. In this work and for design purpose, design value used for the green chip LED is x=0.170 and y=0.700.

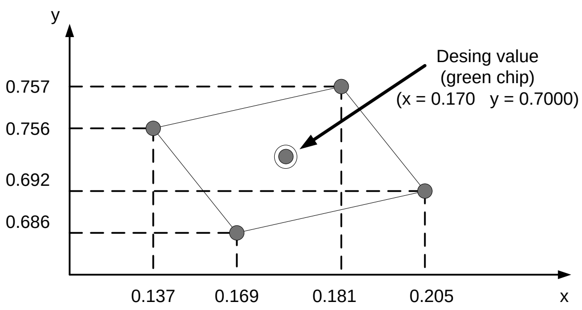

Fig. 4. Dispersion of chromaticity coordinate of green LED chip.

In a similar way, blue chip LED has been chosen in the group 7. Figure shows the dispersion area of the blue chip LED. In this work and for design purpose, design value used for the green chip LED is x=0.135 and y=0.070.

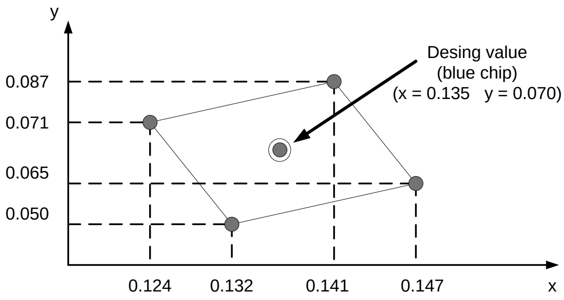

Fig. 5. Dispersion of chromaticity coordinate of blue LED chip.

Finally, red chip LED has not group options. Figure shows the dispersion area of the green chip LED. In this work and for design purpose, design value used for the red chip LED is x=0.693 and y=0.300.

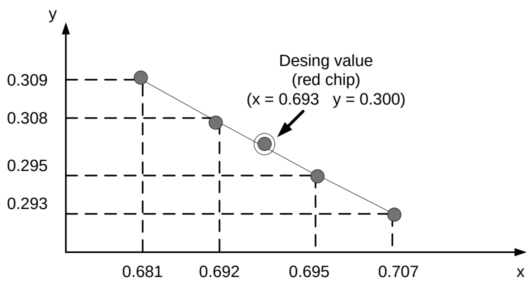

Fig. 6. Dispersion of chromaticity coordinate of red LED chip.

Figures are not in scale. Next figure shows the color area accessible for the LED module in the CIE XYZ chromaticity diagram.

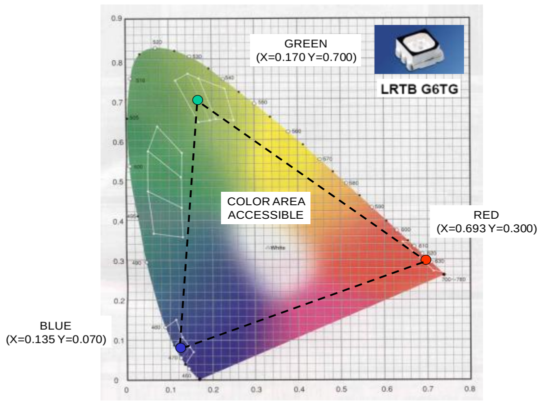

Fig. 6. Region accessible of the LED module in CIE CYZ Chromaticity diagram

III.- BASIC CALCULATIONS

From above considerations, the color matrix [A] with the chromaticity coordinates of the LED module is directly available.

$$[A] = \begin{bmatrix} x_r & x_g & x_b \\ y_r & y_g & y_b \\ z_r & z_g & z_b \end{bmatrix}$$

The particular values for the LED module used are then:

$$[A] = \begin{bmatrix} 0.693 & 0.170 & 0.135 \\ 0.300 & 0.700 & 0.070 \\ 0.007 & 0.130 & 0.079 \end{bmatrix}$$

Using the color matrix [A] the direct problem of which color is obtained for a specific percentage of light from each color chip LED is immediate.

$$[PO] = [A] \cdot [Q]$$

Where, [Q] is the percentage of light for each color and [PO] is the Point of Color Obtained.

$$[Q] = \begin{bmatrix} Q_r \\ Q_g \\ Q_b \end{bmatrix}$$

$$[PO] = \begin{bmatrix} PO_r \\ PO_g \\ PO_b \end{bmatrix}$$

For instance, for a Qr = 100%, Qg=50% and Qb=100%, the PO obtained is:

$$[PO] = \begin{bmatrix} 91.3 \\ 72 \\ 86.7 \end{bmatrix}$$

Obviously, TOTAL = POr + POg + POb = 250%. To obtain the normalized chromaticity coordinate of the PO point it is needed normalize the PO point obtained.

$$[PON] = \frac{[PO]}{TOTAL}$$

Applying this normalization in the above mentioned example.

$$[PON] = \begin{bmatrix} 0.365 \\ 0.288 \\ 0.347 \end{bmatrix}$$

[PON] represents the chromaticity point to be represented in the CIE XYZ diagram.

In a practical vision system, the reverse problem is the interesting one. Which percentage of each light from each chip LED is need for a specific design color.

Obviously, the goal point [GP] must be inside the accessible region for the chip LED in other hand, quantities needed will be not reachable (negative values).

$$[GP] = \begin{bmatrix} GP_r \\ GP_g \\ GP_b \end{bmatrix}$$

The equation to solve is:

$$[GP] = [A] \cdot [Q]$$

Where [Q] are now solution values.

The solution of this equation is:

$$[Q] = [A]^{-1} \cdot [GP]$$

The inverse matrix $[A]^{-1}$ can be easily obtained.

$$[A]^{-1} = \begin{bmatrix} 1.594 & -0.342 & -0.240 \\ -0.693 & 1.601 & -0.023 \\ 0.099 & -0.259 & 1.264 \end{bmatrix}$$

Using the inverse matrix the reverse problem is simple. For instance, for a design [GP] of GPr = GPy = GPb = 0.333 the matrix [Q] obtained is:

$$[Q] = \begin{bmatrix} 0.336 \\ 0.295 \\ 0.369 \end{bmatrix}$$

The meaning of each term is the per unit quantity of light needed for the specified chromaticity coordinate. Qr = 0.336, Qg = 0.295 and Qb = 0.369. Obviously, Qr + Qg + Qb = 1. Trying to obtain a color outside the accessible region for the chip LED, at least one of the Q values will be negatives.

For instance, with [GP] equal:

$$[GP] = \begin{bmatrix} 0.100 \\ 0.600 \\ 0.300 \end{bmatrix}$$

Clearly outside the accessible region, the quantity of light obtained for each color light is:

$$[Q] = \begin{bmatrix} -0.118 \\ 0.884 \\ 0.234 \end{bmatrix}$$

The Qr value (Qr = -0.118) is negative and then it is not possible to implement.

IV.- CONTROL CIRCUITRY

The LED array will be controlled using a classical PWM driver with constant switching frequency (350 Hz) and PWD control in order the adjust the light level of each chip LED to the specified value.

Figure shows the basic elements of the control circuitry.

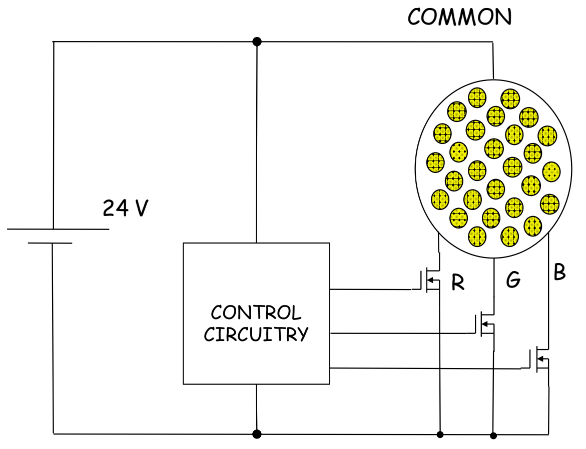

Fig. 7. LED driver philosophy

The basic connection of each LED chip is also shown in the next figure.

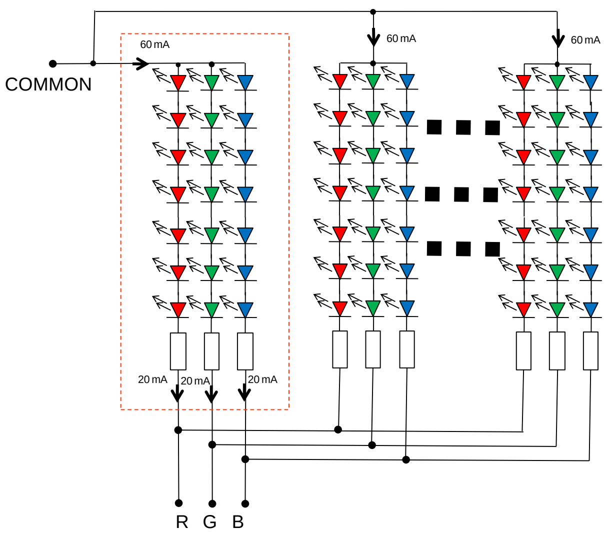

Fig. 8. Basic connection of each LED chip.

The nominal current across each LED chip is fixed by the electronic circuit (ILEDr, ILEDg, ILEDb). In the particular design presented in this work, the nominal current across each LED chip is the same and equal to 20 mA.

ILED = ILEDr = ILEDg = ILEDb = 20 mA

Next figure shows a generic waveform for a LED chip, shown the PWM control. The control parameter used for the control circuitry is the duty cycle (d). The value of each duty cycle (dr,dg and db) for a specific design point must be obtained and fixed for the electronic circuitry.

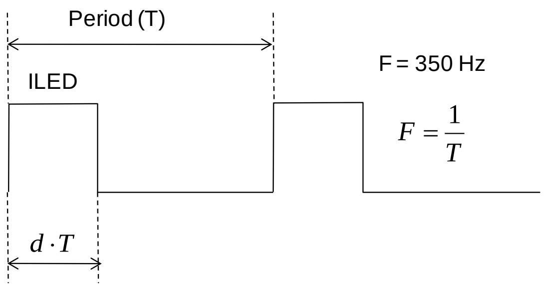

Fig. 9. Generic LED control waveform.

The first step to obtain duty cycle values is to estimate the nominal power in each LED chip. The voltage drop in each LED chip at nominal current (ILED) is easily obtained. Values obtained are:

VLEDr = 2.1 V, VLEDg = 3.2 V and VLEDb = 3.2 V

With ILED and VLED values the nominal power (PLED) in each LED chip can be easily obtained:

PLEDr = VLEDr.ILEDr

PLEDg = VLEDg.ILEDg

PLEDb = VLEDb.ILEDb

With the particular values of the LRTB-G6T6 LED module, values obtained are:

PLEDr = 42 mW

PLEDg = 64 mW

PLEDb = 64 mW

Using the optical efficiency (OE) of each LED chip, the nominal luminous flux is obtained:

LMr = OEr.PLEDr

LMg = OEg.PLEDg

LMb = OEb.PLEDb

In this particular application values are:

OEr = 43 lm/W

OEg = 36 lm/W

OEb = 11 lm/w

And then:

LMr = 1.806 lm

$$LMg = 2.304 \text{ lm}$$

$$LMb = 0.704 \text{ lm}$$

LM represents the nominal luminous flux for each LED chip, that is to say, the quantity of light with duty cycle (d) equal 1. In a particular case, the duty cycle (d) required in each LED chip for a specific quantity of light [Q] needed, can be easily obtained:

$$d_r = \frac{Q_r}{LM_r}$$

$$d_g = \frac{Q_g}{LM_g}$$

$$d_b = \frac{Q_b}{LM_b}$$

For instance, in the previous example, in order to obtain the chromaticity point [GP]=[0.333, 0.333, 0.333] the quantity of light required for each color in per unit values are [Q] = [0.336, 0.295, 0.369] and the the duty cycle needed in each LED chip will be [d] =[dr, dg, dg] = [0.186, 0.128, 0.524].

In this point it is important to emphasize different light levels cab be obtained with the same chromaticity values. In other way, maintaining the proportionality of duty cycle values, the same chromaticity point is obtained with different total lamp lumen level.

In a practical way, the point in which the total lamp is maximum for a specific chromaticity value is looking for the set duty cycle values in which one of their has the maximum value ([dmax] = [drmax, dgmax, dbmax]).

$$d_{\max} = \max(d_r, d_g, d_b)$$

$$d_{r\max} = \frac{d_r}{d_{\max}}$$

$$d_{g\max} = \frac{d_g}{d_{\max}}$$

$$d_{b\max} = \frac{d_b}{d_{\max}}$$

In the previous example, the initial set of values [d]=[0.186, 0.128, 0.524] implies a dmax = 0.254 and then [dmax] = [0.355, 0.244, 1]. In this point, the values dbmax = 1 implies maximum duty cycle for this LED chip.

Finally, the total luminous flux of the lamp (LMT) for a specific chromaticity point and with a total number of LED modules (N) in the lamp can be obtained using the next expression:

$$LMT = N.(dr.LMr + dg.LMg + Db.LMb)$$

For instance, with N = 120 and [d] = [dmax] = [0.355, 0.244, 1] the luminous flux obtained in the lamp is the 229 lm.

As curiosity, the lamp with N = 120 chip modules and with all duty cycle to its maximum values [d] = [1,1,1] has a luminous flux of 577.7 lm. In this absolute maximum lumen level the chromaticity value obtained is [0.361, 0.458, 0.181].

IV. EXPERIMENTAL PROTOTYPE

A first prototype of LED lamp for the pattern recognition workbench has been built using commercial modules.

The lamp is composed for 120 LED modules (then 120 red LED, 120 green LED and 120 blue LED). For the prototype 4 sets of the linear module from OSRAM have been used (reference OS-MM01M-RGB-B7). An electronic driver from OSRAM has been also used (Reference OPTOTRONIC OT RGB). And finally a commercial power supply.

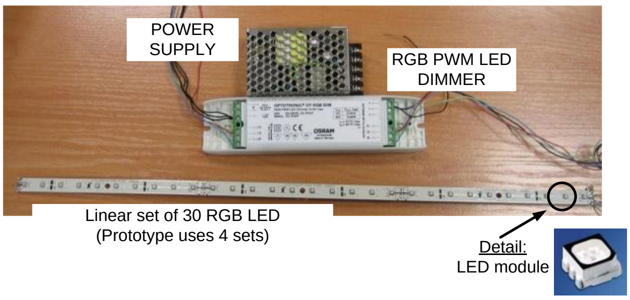

Fig. 10. Prototype elements.

In next stage of the project a custom made prototype of lamp with be built using a MICROCHIP MCU with direct interface to control computer with vision algorithms.

Theoretical versus experimental lumens and chromaticity coordinates have been measured and compared using a sphere photometer with 1 m of diameter and a LABSPHERE photometry equipment.

V. CONCLUSION

A lighting system specifically designed for a pattern recognition system has been proposed and designed. A complete methodology has been developed in order to obtain theoretical chromaticity coordinates and luminous flux under computer control. The proposed system is suitable to chose the correct illuminations conditions of the scene in order to optimize the vision algoritms. The prototype has been built and tested. A future version of whole lamp system most compact are now under development assuming design condictions included in this work.

ACKNOWLEDGMENTS

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