Lighting System Control for Everyday and Therapeutic Purposes

Viktor Mashkov, Yulka Petkova

Abstract — The goal of this article is to provide a method for controlling an LED-based, scalable lighting system. It is known that the spectral characteristics of ambient light affect the natural production of hormones cortisol and melatonin and to a great extent govern the circadian rhythm of living organisms. We provide a solution that allows controlling certain spectral characteristics of the illuminator's luminous flux in order to mimic those of daily solar radiation. Into account are also taken users' age group, their momentary desire for the magnitude of the luminous flux and possibilities for therapeutic applications aiming to reduce some hormonal imbalances. Damaging the natural circadian rhythm of living organisms has been known to cause a number of short and long term side-effects, increase risk of dementia, certain types of cancer and other neurodegenerative deceases.

Keywords — LED Lighting, Artificial Light Control, Circadian Rhythm.

I. INTRODUCTION

Through recent years, LED lights have rapidly progressed, offering massive energy savings, reliability and management possibilities. Lately, a growing interest in the latter has occurred. In 2018, the Scientific Committee on Emerging and Newly Identified Health Risks published a paper on "Health Effects of Artificial Light" where possible health risks of different artificial light sources are analyzed [1]. Proposed is regulating different spectral characteristics of light in order to achieve greater cognitive, mood and general health outcomes. Since then, increasing attention has been given to managing the correlated color temperature of the luminous flux of an artificial light source to mimic the diurnal cycle of the summer sunshine [1, 2]. Our aim is to offer a solution which provides control over the correlated color temperature and luminous flux of an LED-based artificial light system with personalization in mind without the use of complex and expensive hardware.

II. LITERATURE ANALYSIS

Taking into account numerous research [1-7 and many others], we gather the relevant parameters for this paper. It is shown that human circadian rhythm has a strong dependency on spectral characteristics of ambient light [1, 2]. In addition, with age, the eyes' crystalline lens acquires a yellow tint, affecting perception of color [3]; hence adjustments based on user age are needed. In this paper users are divided into three separate age brackets: young children, teens to middle aged and elderly. Different age brackets affect the peak Correlated Color Temperature (CCT) of the simulated solar cycle. The first age bracket is categorized with little to no yellow tint of the crystalline lens (peak CCT does not exceed 4500K), the second - with little to moderate (peak CCT does not exceed 6500K) and the third - with moderate to high (peak CCT can reach 7500K) [3]. An additional regime of function is added for therapeutic purposes - users are to use it for a limited amount of time - anywhere from 30 minutes to 2 hours for Seasonal Affective Disorder (SAD) management [4].

Obtaining desired CCT is heavily reliant on the use of the CIE 1931 XYZ color and xy chromaticity space and the McCamy xy chromaticity to CCT cubic approximation. When mixing colors we deploy the vector properties of the aforementioned color space - addition of colors and determination of resulting characteristics are reduced to the corresponding vector operations -

Viktor Mashkov, Technical University of Varna, Bulgaria.
Yulka Petkova (advisor), Technical University of Varna, Bulgaria.

addition and multiplication. Assuming X, Y, Z color coordinates, the coordinates at which its directrix pierces the chromaticity plane (the xy chromaticity coordinates) are calculated as follows:

$$x = \frac{X}{X + Y + Z} \quad y = \frac{Y}{X + Y + Z} \quad z = \frac{Z}{X + Y + Z}$$

III. OBJECT, SUBJECT, AND METHODS OF RESEARCH

LED manufactures provide datasheets [6], containing chromaticity coordinates (x, y) and luminous flux (Y), depending on operating current, voltage and temperature of the p-n junction. With such data in the system we can calculate the resulting color using the formulas:

$$X_{\Sigma} = m * x_W * \left(\frac{Y_W}{y_W}\right) + n * x_B * \left(\frac{Y_B}{y_B}\right)$$

$$Y_{\Sigma} = m * Y_W + n * Y_B$$

$$Z_{\Sigma} = m * \left(\frac{Y_W}{y_W}\right) * (1 - x_W - y_W) + n * \left(\frac{Y_B}{y_B}\right) * (1 - x_B - y_B)$$

where X_{Σ}, Y_{Σ} and Z_{Σ} are the resulting color coordinates. We can then calculate the xy chromaticity coordinates for the new color.

When a system has achieved the appropriate CCT, but a user wishes to change the luminous flux we can, while maintaining the chromaticity coordinates, adjust both lighting channels by a coefficient, leveraging the vector nature of how our system processes colors (Fig. 1).

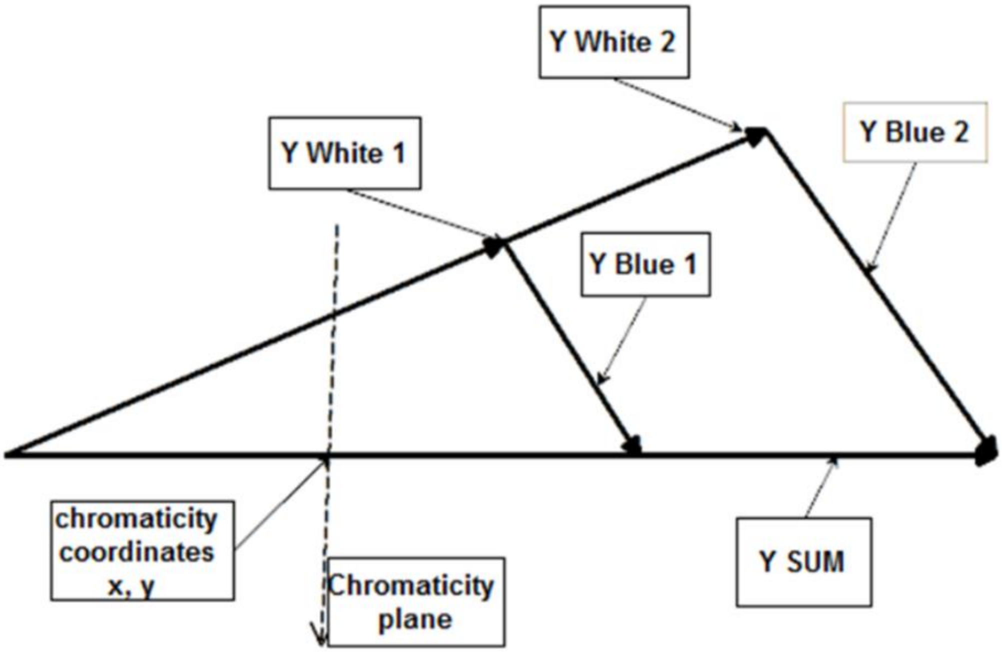

Fig. 1. Y White1, Y White2 – luminous flux of white LEDs before and after change, lm; Y Blue1, Y Blue2 - luminous flux of blue LEDs before and after change, lm; Y SUM - resulting luminous flux, lm

Controlling the LEDs' luminous flux can be achieved with the usage of a true constant current driver. Such drivers allow control over a dedicated PWM channel, therefore operating current can be accurately set (RSE < 1%).

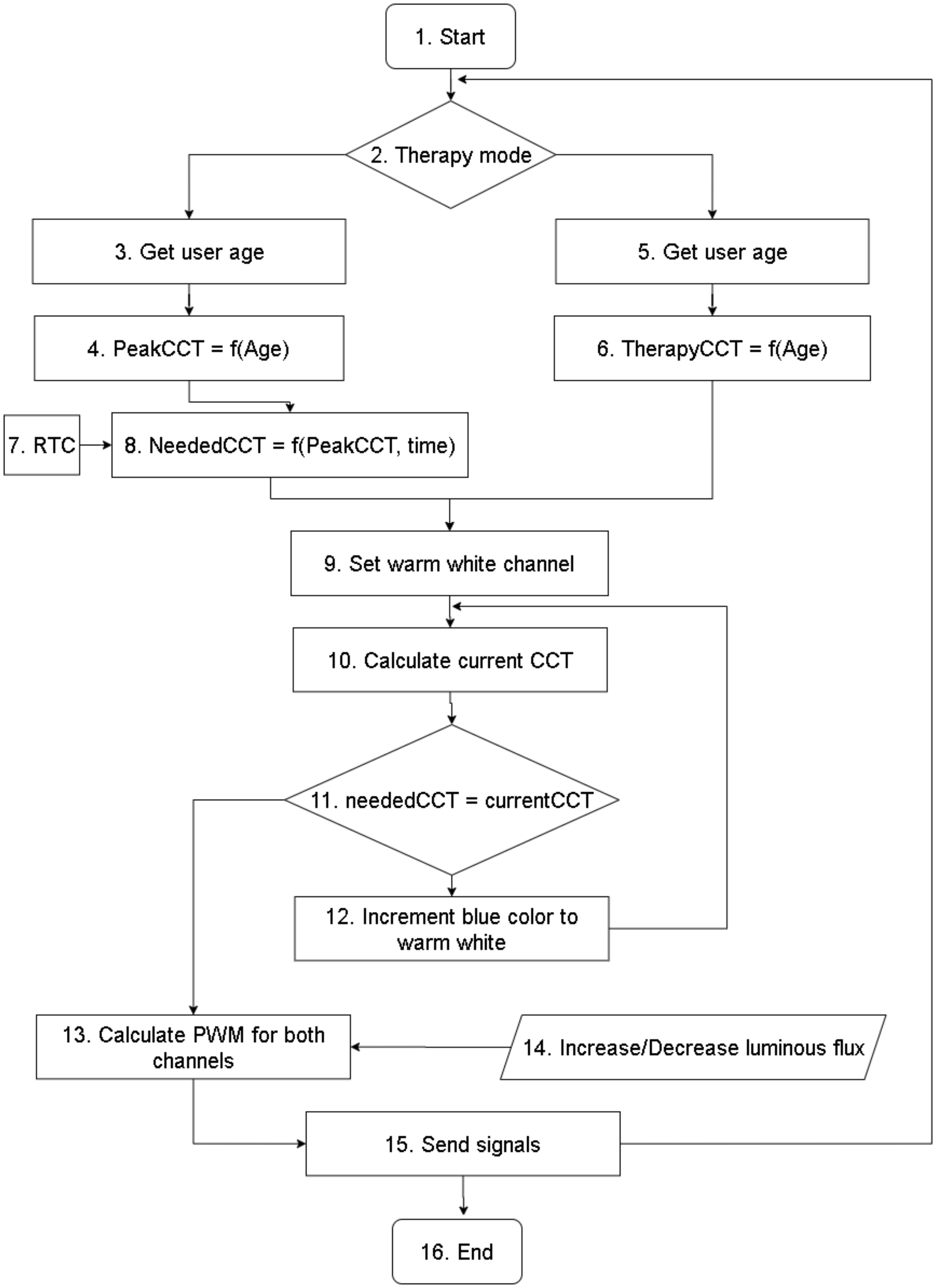

Fig. 2. Block diagram of the used algorithm

The system's block diagram is shown in Fig. 2. Firstly, users choose normal or therapeutic function (block 2). The system then calculates appropriate CCT - current CCT for normal mode, as a function of time and the user's age (blocks 3, 4, 8) or as a function of age for therapy mode (blocks 5, 6). Next, calculations are initialized with the lowest achievable by the system CCT - that of the warm white lighting channel (block 9). With respect to the characteristics of the used LEDs, current CCT is calculated (block 11). Then, the algorithm "increments" blue color until a satisfying CCT is reached (blocks 10, 11, 12). The resulting color parameters are converted to PWM signal and sent to the driver circuit depending on the exact hardware used (blocks 13, 15). At this stage we can increase or decrease the overall luminous flux of the lights without changing their spectral composition (block 14).

To achieve accurate relative luminous flux control, further exploration is needed. Manufacturers provide a graph, containing relative luminous flux as a function of operating current (Fig.3) [6].

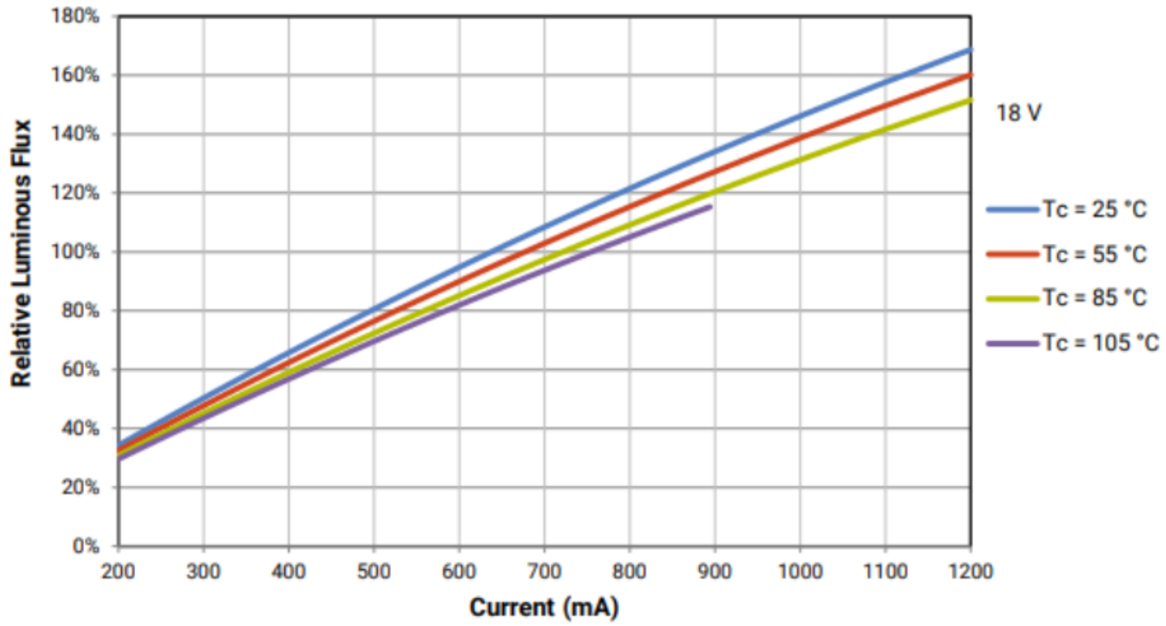

Fig. 3. Relative luminous flux as a function of operating current for CREE CXB1512 2700K, 80CRI LED modules [6].

After the appropriate LEDs and their operating temperatures are chosen we can approximate the current needed to achieve a certain relative luminous flux on a per-case basis. It should be noted that relations between relative luminous flux and current do not present a perfect linear relation, but after further experimental investigation of our linearization method we found minimal deviation ($R^2 > 0.99$), which makes the approximation perfectly acceptable for this paper's use case.

The software part of this project must provide the following capabilities:

- Normal lighting mode – used for everyday purposes with the goal of imitating summer solar radiation. Can be customized based on users' age as follows:
  - Mode 1 – Users are children. The system limits radiation in the blue spectral range (under 500nm). Peak CCT does not exceed 4500K.
  - Mode 2 – Users are teens and adults. Peak CCT can reach 6500K.
  - Mode 3 – Users are elderly. Peak CCT can reach 7500K.

- Multiple therapeutic lighting modes – used for specific situations (battling Seasonal Affective Disorder, depressive states, dementia etc.).
- User and touch-friendly interface that allows users to manipulate the system accordingly.
- This paper proposes a solution based on the Raspberry Pi computer. In addition, to achieve the set goals we used:
- 3 CREE CXB1512 LED modules. These modules provide adequate luminous flux (3000lm at nominal current) and 2700K CCT.
- 8 CREE XQE Blue LEDs. Combined with the aforementioned warm white modules, the system can achieve a wide range of correlated color temperatures at a variety of luminous fluxes.
- 2 MEANWELL LCM-60 LED drivers. The drivers allow control of the current through the LEDs via PWM signals, generated by the Raspberry Pi.

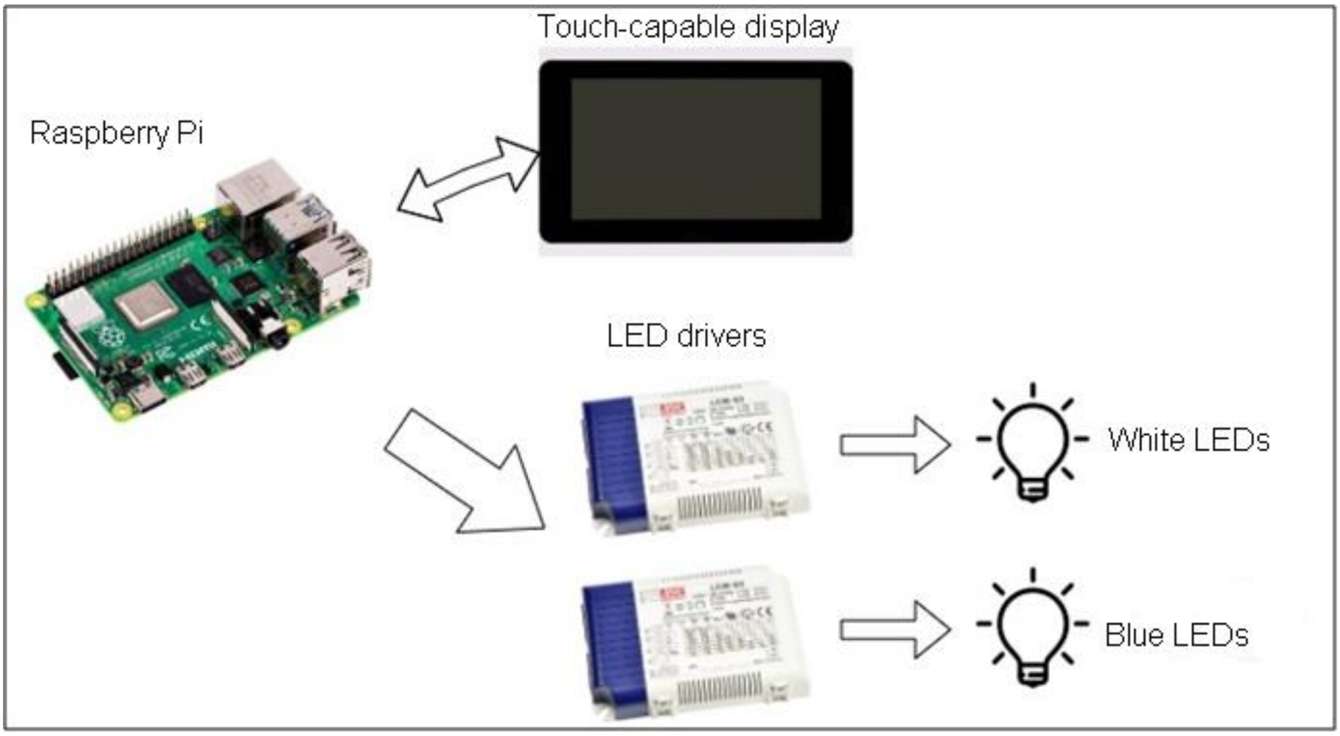

Fig. 4. Block diagram of the main system modules interacting with each other.

Testing different parameters of the system was achieved using:

- Spectroradiometer Stellar Net BLACK-Comet VIS-NIR – Allows testing spectral characteristics of the luminaire.

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- Integrating sphere with a 1m diameter – Allows probing for spectral characteristics.
- A number of oscilloscopes – Allow testing the control PWM signals in different situations.
- Other electronic measuring equipment.

IV. RESULTS

A number of experiments were performed, concerning the accuracy of the PWM control signals and the overall spectral characteristics the system provides.

The first set of experiments consisted of examining the control signals for both the warm white and blue channels via the use of an oscilloscope. Different working modes were selected and the relation between the desired control signals, the actual control signals and the desired CCT values was examined.

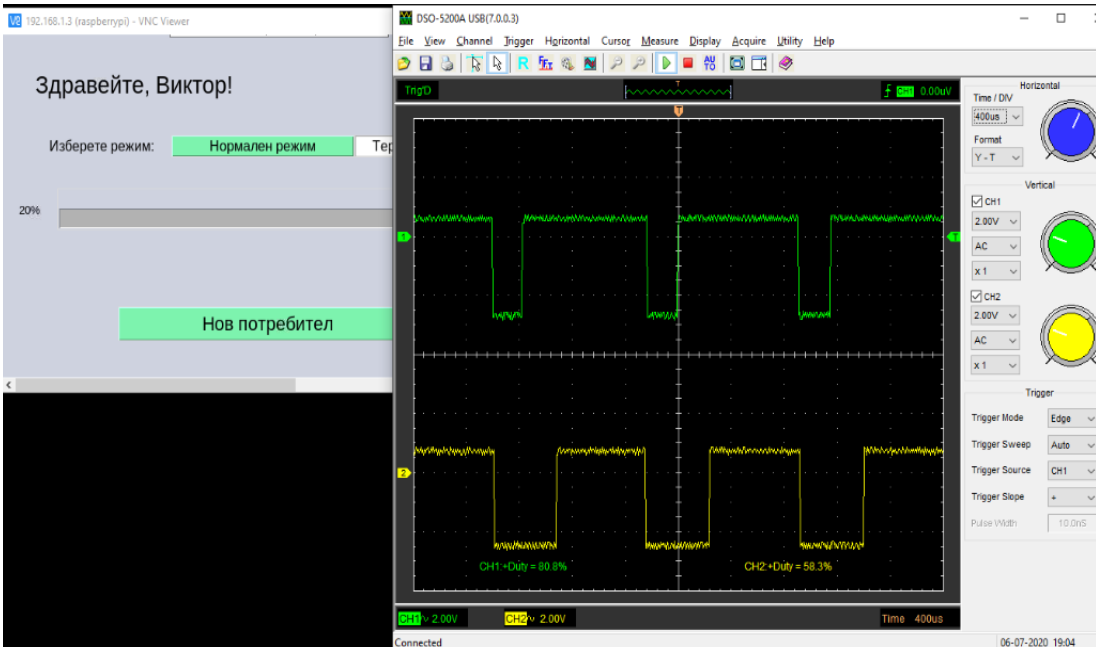

Fig. 5. Exemplary result for therapeutic mode selected (CCT – 7500K, Relative luminous flux – 90%)

The second set of experiments was associated with the spectral characteristics of our illuminator. An integrating sphere and a spectroradiometer were used to investigate changes in photometric characteristics in relation to changing user parameters.

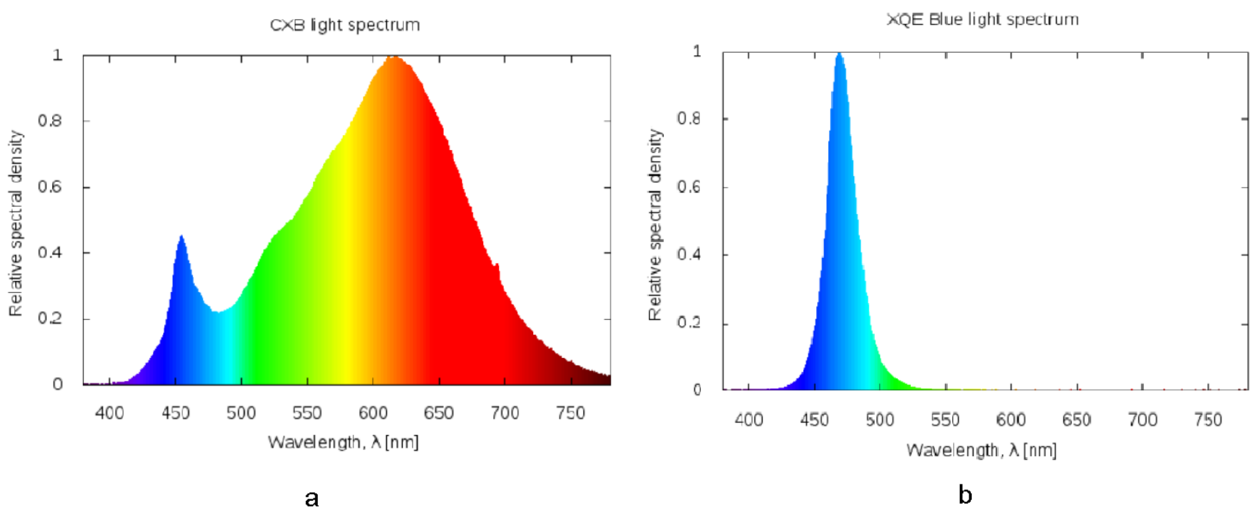

Fig. 6. Experimentally obtained spectral characteristics for used LEDs (5a – CXB1512 warm white, 5b – XQE Blue)

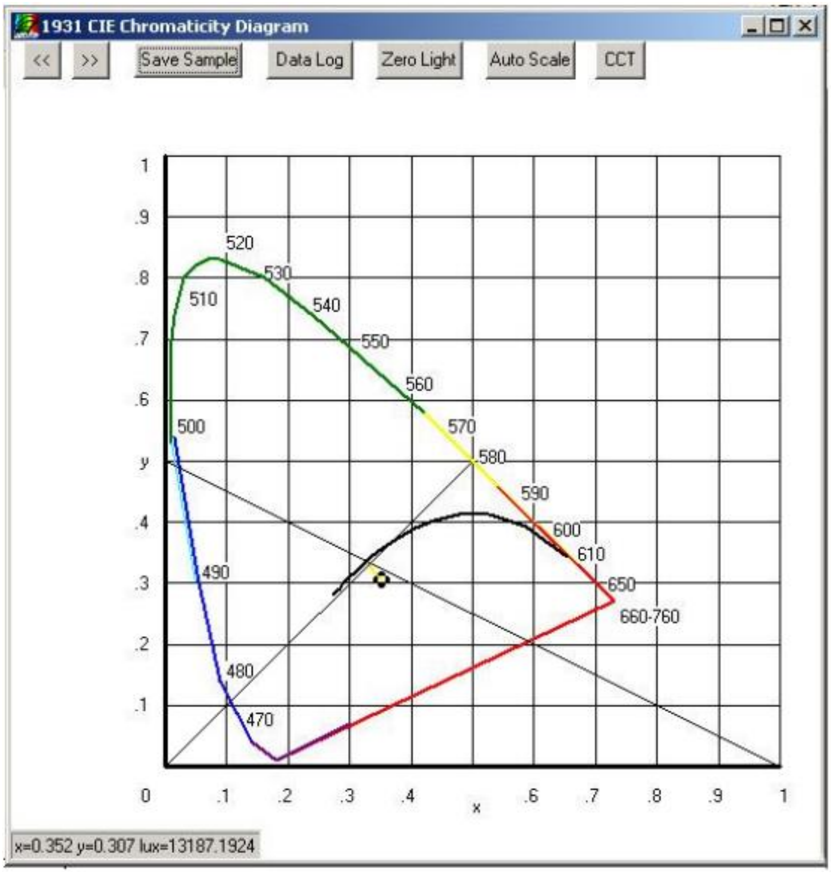

Fig. 7. Result showing spectral and photometric characteristics of our luminaire for desired CCT – 4400K, measured CCT = 4450K, I_{white} = 350mA, I_{blue} = 185mA, luminous flux Y_{Σ} = 1404lm

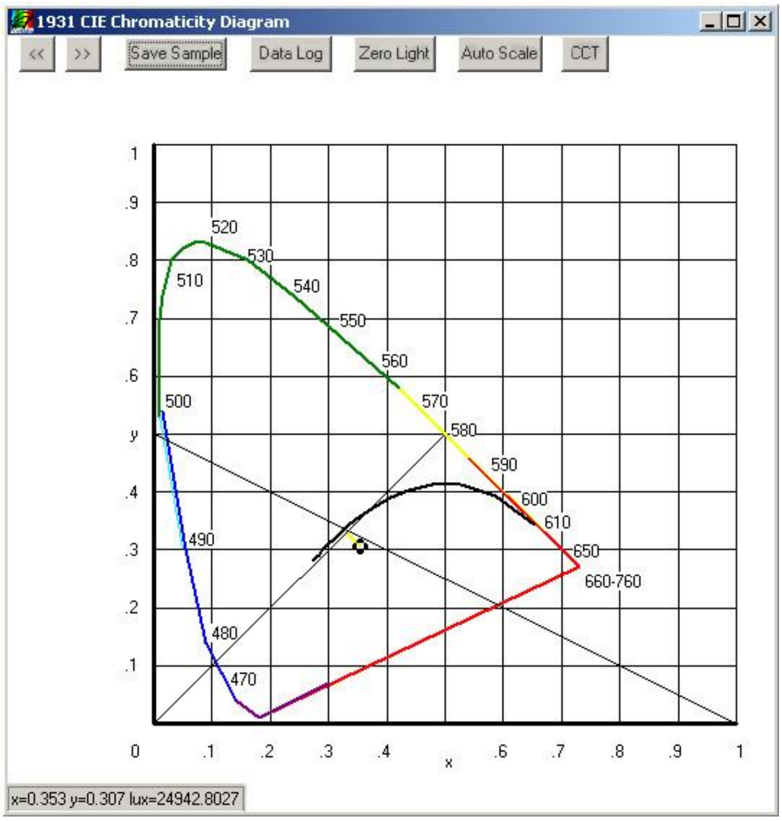

Fig. 7. Result showing spectral and photometric characteristics of our luminaire for desired CCT – 4400K, measured CCT = 4369K, Iwhite = 700mA, Iblue = 360mA, luminous flux YΣ = 2666lm

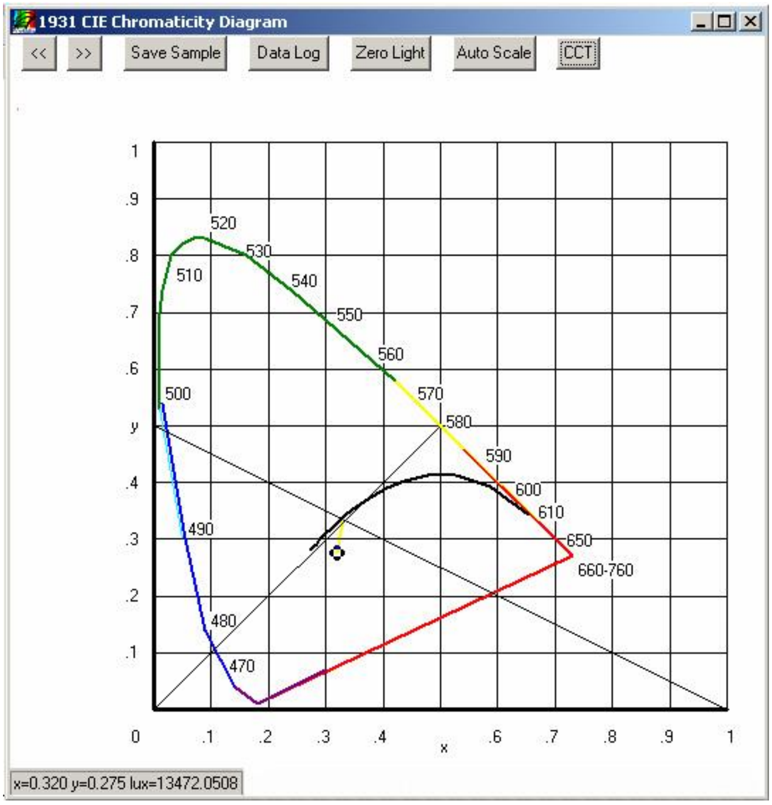

Fig. 8. Result showing spectral and photometric characteristics of our luminaire for desired CCT – 6500K, measured CCT = 6490K, Iwhite = 350mA, Iblue = 285mA, luminous flux YΣ = 1432lm

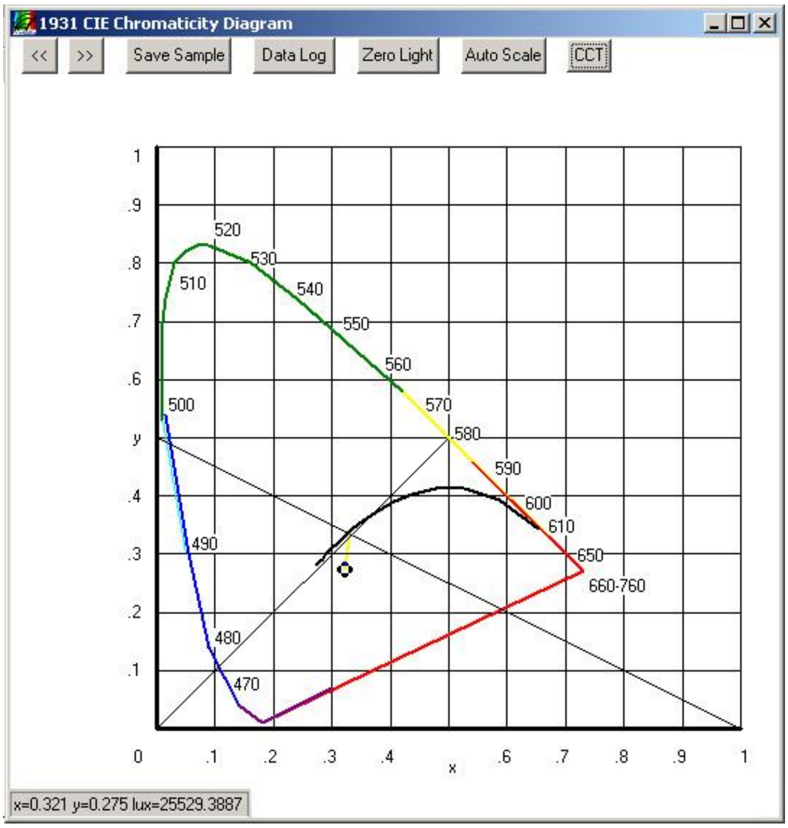

Fig. 9. Result showing spectral and photometric characteristics of our luminaire for desired CCT – 6500K, measured CCT = 6435K, Iwhite = 700mA, Iblue = 632mA, luminous flux YΣ = 2709lm

The following table shows results for two set CCTs (4400K and 6500K). The relative luminous flux is changed through the system's user interface. The actual luminous flux, correlated color temperature, current and Duv are measured:

CXB1512 I, [mA]	XQE Blue I, [mA]	Flux, [lm]	x	y	CCT, Desired, [K]	CCT, Measured, [K]	Duv
350	185	1404	0,352	0,307	4400	4450	0,027
400	205	1577	0,352	0,307	4400	4315	0,026
500	255	1904	0,353	0,308	4400	4403	0,027
600	310	2256	0,353	0,307	4400	4402	0,027
700	360	2666	0,353	0,307	4400	4369	0,028
350	285	1432	0,320	0,276	6500	6490	0,032
400	328	1632	0,320	0,275	6500	6484	0,032
500	420	2014	0,321	0,275	6500	6480	0,032
600	520	2384	0,321	0,275	6500	6426	0,032
700	632	2709	0,321	0,275	6500	6435	0,032

V. CONCLUSIONS

A lighting management system for controlling the luminous flux characteristics of an LED based luminaire was developed and presented. This paper offers a relatively simple, reliable and scalable solution to adaptive lights. Numerous experiments showed sufficient accuracy without the need for a feedback system, keeping our solution low-cost. The presented system allows CCT control of the luminous flux as well as constant CCT while changing luminous flux. Taken into account are relevant user parameters.

VI. REFERENCES

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