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DESIGN OF A SELF-ADAPTED LED DESK LAMP BASED ON TCS3414CS

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ABSTRACT

In this paper, a design of a self-adapted LED desk lamp is presented. The illuminance on the work plane and colour temperature of the hybrid light are measured by the multi-channel colour sensor TCS3414CS. The MCU embedded in the lamp will adjust the LED drivers' output to maintain constant illumination. Experimental results show that, no matter how the ambient light changes under different scenes, the lamp can still provide satisfactory lighting condition with both illuminance and colour temperature adjusted to a predefined value, leading to a more comfortable user experience.

Key words: LED desk lamp, illumination, CCT, colour sensor, dimming control

1. INTRODUCTION

With the rapid development of LED technology, people are paying more and more attention on quality, comfort and environmental friendliness of illumination rather than brightness and cost. Desk lamps are the most widely used supplementary lighting devices in our daily life. There are two main types of LED desk lamp in current market [1]: traditional lamps without dimming function and smart lamps whose brightness and colour can be manually set. However, once ambient light changes, the former cannot maintain a constant illumination on the work plane. And because the adjustment solely depends on users' intuitive feelings, the latter type may provide a too high or too low lighting level, causing damage to human's eyes if it is used for a long time. And the by-hand adjustment is contrary to the intelligent, humanized and low-carbon design concept of modern household appliances. Besides, users have various colour temperature preferences and colour requirements are not always the same in different scenarios. For example, warm light is more suitable for leisure time reading, while light with high colour temperature can keep people's mind active when they are working [2]. In order to better meet the needs for quality lighting, this paper design a self-adapted LED desk lamp capable for both illuminance and colour temperature adjustment. When the environmental light changes, the lamp is able to adjust the LED output to provide a constant illuminance level and keep the correlated colour temperature of the hybrid light (ambient light & LED) to a predefined value in the meantime.

2. DESIGN OVERVIEW

The hardware design of the desk lamp consists of a micro controller, LED drivers, a colour sensor

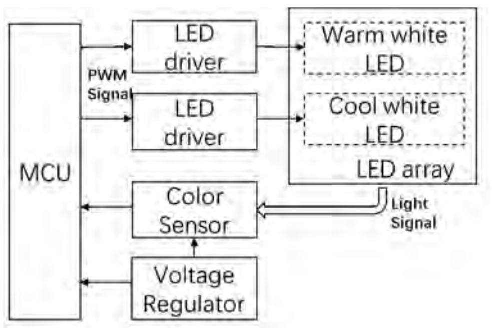


Fig.1. Overview of the desk lamp

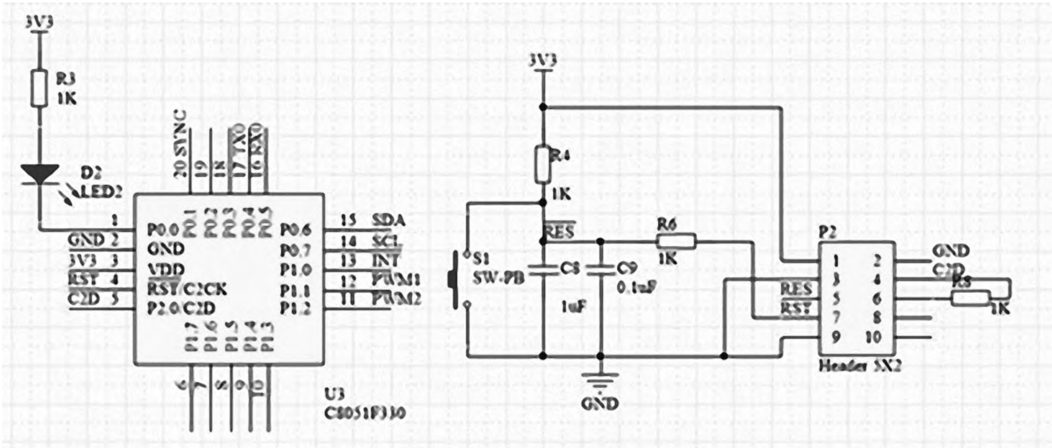


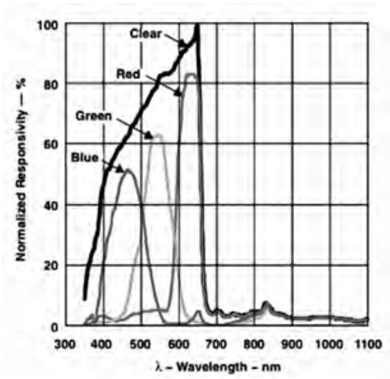
Fig. 2. MCU circuit and its programming interface

[3,4], voltage regulators and a LED array, as Fig. 1 shows.

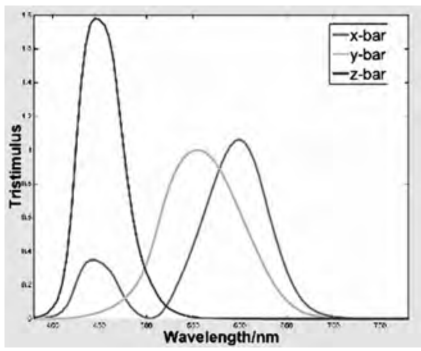
The LED array is comprised of 2 kinds of LED with different colour temperature in order to implement the CCT adjustment feature. To extend the range of light colour control as well as meet the output flux requirement, Cree XLamp XPE series is selected for its spectra diversity and high performance. In this design, we choose 2600K and 6500K LED whose power can be up to 2W per chip.

The colour sensor located on the lamp holder can receive the hybrid light, and send the information to the MCU. Then the MCU will calculate the hybrid light CCT and illuminance on the work plane, and compare the results with preset values to adjust the LED output to realize adaptive control.

For the sake of safety, the input voltage of the desk lamp is restricted to 12V with an external AC-DC adapter. Since the rated voltage for both the



a)



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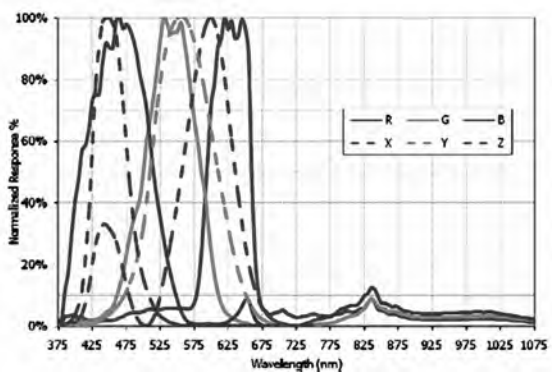

c)

Fig. 3. (a) Response curves of TCS3414CS; (b) Tristimulus of human eyes; (c) Normalized curves comparison

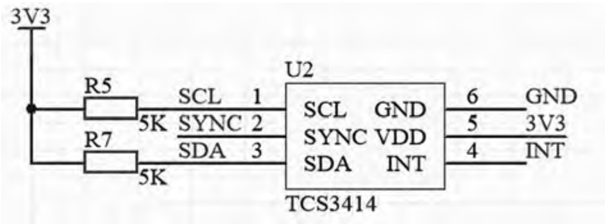

Fig. 4. Colour sensor TCS3414CS

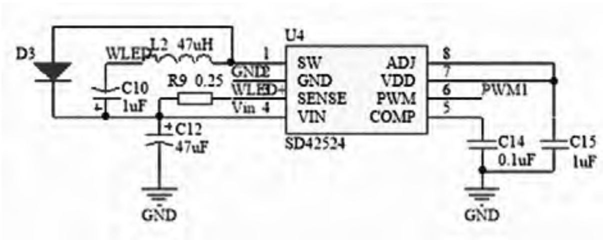

Fig.5. LED driver

MCU and the colour sensor is 3.3V, extra voltage regulators are implemented in the PCB board.

3. HARDWARE DESIGN

3.1. Control circuit

As the core of the hardware design, the controller is responsible for PWM signals generation, communication with the colour sensor and output adjustment based on the control algorithm. In this design, we choose Silicon Laboratories' 8-bit MCU8051F330, which contains a high-speed pipelined 8051-compatible microcontroller core and various peripherals, Fig.2. Apart from many kinds of digital interfaces such as SMBus, UART and SPI integrated, C8051F330 is rich in counter resource and able to generate 4-independent-channel PWM signals, which meets our design requirements perfectly.

3.2. Colour sensor

In order to obtain the illuminance on the work plane and CCT of hybrid light, a 4-channel digital colour sensor, TCS3414CS, produced by AMS, is used in this design. This sensor includes an 8×2 array of filtered photodiodes, analogue-to-digital converters, and control functions on a single monolithic CMOS integrated circuit. Of the 16 photodiodes, 4 have red filters, 4 have green filters, 4 have blue filters, and 4 have no filter (clear). Fig. 3(a) shows the spectral responsivity of TCS3414CS, Fig. 3(b) is the tristimulus curves of human eyes and Fig. 3(b) is the comparison of the normalized curves.

Since the response curve have very similar peak wavelength and FWHM with tristimulus curve, MCU can solve for CCT and illuminance by Matrix operations and use the results as the regulation basis. Equation 1 shows the calculation of illuminance and Equation 2–5 illustrate how to acquire CCT value [5,6]. Where *R, G* and *B* are the integral response of the filtered channels of TCS3414CS respectively.

$$E=(-0.32466)R+(1.57837)G+(-0.73191)B. \quad (1)$$

$$\begin{cases} X=(-0.14282)R+(1354924)G+(-0.95641)B \\ Y=(-0.32466)R+(1..57837)G+(-0.73191)B, \\ Z=(-0.68202)R+(0.77073)G+(0.56332)B \end{cases} \quad (2)$$

$$\begin{cases} x=X/(X+Y+Z) \\ y=Y/(X+Y+Z) \end{cases}, \quad (3)$$

$$n=(x-0.3320)/(0.1858-y), \quad (4)$$

$$CCT=449n^3+3525n^2+6823.3n+5. \quad (5)$$

The MCU communicates with the colour sensor through I^2C bus as Fig. 4 shows. The sampling integration time is set to 154 ms.

3.2. LED driver

The LED driver plays a significant role in the desk lamp design. General requirements for LED drivers are high efficiency and good control accuracy [7]. In this design, we take advantages of Silan's high performance step-down PWM control LED driver, SD42524, to modulate the light output. With the 12 V DC input voltage, the LED drivers can achieve 1A continuous output current with thermal shutdown protection and current restriction. Two SD42524 chips are used for independent adjustment of the two different color temperature LEDs. To simplify the control algorithm, the sampling resistance of the LED drivers are tuned to make the total flux of 2600K LEDs equal to that of 6500K LEDs when the duty cycles are set to 1 for both. Fig. 5 is the circuit of LED driver.

4. DIMMING STRATEGY

A two-stage dimming strategy is adopted in this design to provide target illuminance on work plane, adjust the CCT of hybrid light to a certain degree and keep stable lighting condition.

First of all, the MCU will acquire the current illuminance through the colour sensor and compare it with the target value.

$$e = E_m - E_t. \tag{6}$$

Where E_m and E_t are the target and measured illuminance. If the absolute value of e exceeds the threshold, the MCU will increase (when e>0) or decrease (when e<0) the output power of both LED drivers by same percentage simultaneously. Usually after several rounds of negative feedback regulation, the gap between measured illuminance and target value will be narrowed down to the threshold.

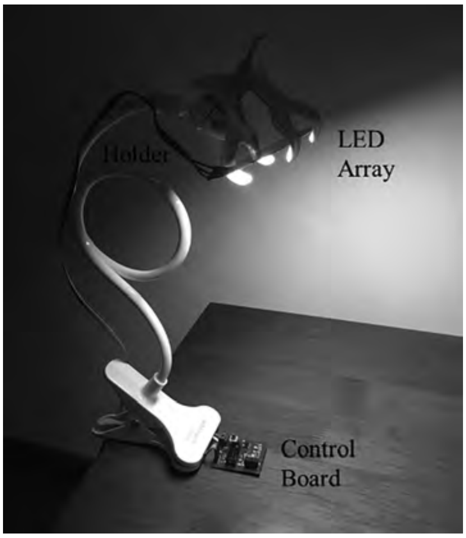

Fig. 6. The testing experiment

Table 1. The illumination and CCT values under different scenes in Experiment 1

Scenes	Illuminance, lx (LED Off)	CCT, K (LED Off)	Illuminance, lx (LED On)	CCT, K (LED On)
Turn off all other lights at night	0	N/A	495	4033
Turn on the remote fluorescent lamp	208	3123	506	3965
Turn on the nearby fluorescent lamp	385	3353	497	3950
Open windows at noon	244	4698	513	4076

Once the illuminance requirement is met, the dimming strategy goes into the next stage to realize a constant CCT value of the hybrid light. Similarly, the error between real CCT value and preset value is solved out first. Then if it goes beyond the CCT threshold, the MCU will adjust the output of the two LED drivers by same percentage but in opposite direction. For instance, if the measured CCT is higher than the target, the output of warm white LEDs will increase while the cool white ones are turned down and vice versa.

Proportion control algorithm is adopted for both illuminance and CCT adjustment [8] to fulfil smoothly modulation. Taking illuminance regulation as an example, the control object is the duty cycle of the PWM signal and it is calculated according to the following equation:

$$D(n+1) = D(n) + P \times e. \tag{7}$$

$D(n)$ is the current duty cycle, $D(n+1)$ is the duty cycle for the next moment and P is the proportionality factor. The P value can't be set too high or too low, because it will cause the output unstable or make the MCU takes more rounds to hit control targets. In this design, we used the empirical equation below to solve out the P value.

$$P = \frac{0.0002(E_t - E_a)}{E_{LED}}. \tag{8}$$

Where E_a is the illuminance of ambient light, which can be measured before LEDs are turn on. And E_{LED} is the maximum illuminance that one single channel LEDs can produce on the work plane. The same proportionality factor is used for CCT control algorithm.

Table 2. The illumination and CCT values under different scenes in Experiment 2

Scenes	Illuminance, lx (LED Off)	CCT/K (LED Off)	Illuminance, lx (LED On)	CCT/K (LED On)
Turn off all other lights at night	0	N/A	746	5023
Turn on the remote fluorescent lamp	200	3221	756	5095
Turn on the nearby fluorescent lamp	392	3307	743	4952
Open windows at noon	256	4701	771	5026

5. SIMULATION EXPERIMENT AND RESULTS

Two sets of simulation experiments were conducted to verify the control function. As shown in Fig. 6, the LED array is clamped by an adjustable holder. The control board is placed near the holder on the desk. And the distance between the LED array and the colour sensor mounted on the PCB board is around 50 cm, which is equal to typical reading distance.

Experiment 1:

Target illuminance: 500 lx, threshold: 50lx;

Target CCT: 4000K, threshold: 100K

The test results are shown in Table 1.

Experiment 2:

Target illuminance: 750 lx, threshold: 50lx;

Target CCT: 5000K, threshold: 100K

The test results are shown in Table 2.

From the test results, we can figure out that the fluctuation of illumination is restricted within 3 % and the CCT shift is limited to 2 % under different situations. The output will be stable within 20 rounds of feedback regulations, that is, in less than 3 seconds.

6. CONCLUSION

A design of a self-adapted LED desk lamp is presented in this paper. The illuminance on the work plane and correlated colour temperature of the hybrid light are measured by the multi-channel colour sensor TCS3414CS. Based on the sensor reading, the embedded MCU will adjust the LED drivers' output to maintain constant illumination. Experimental results show that, no matter how the ambient light changes under different scenes, the LED desk lamp can still provide satisfactory lighting condition with both illuminance and correlated colour temperature adjusted to a predefined value, leading to a more comfortable user experience. The specific mechanical structure of the lamp is not designed in this paper. In actual production, the control board can be enveloped in the lamp base with a small hatch over the colour sensor, and then the light can be measured.

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