A PORTABLE RGB LED LIGHT SOURCE WITH COLOR CONTROL MECHANISM FOR BACKLIGHTING APPLICATION

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by

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LIST OF ABBREVIATIONS

ADC	Analog-to-Digital Converter
CCFB	Color Coordinate Feedback
CCFL	Cold Cathode Fluorescent Lamp
CCR	Continuous Current Reduction
CCT	Correlated Color Temperature
CIE	International Commission on Illumination
CRI	Color Rendering Index
DC	Direct Current
DIP	Dual Inline Package
EEPROM	Electrically Erasable Programmable Read Only Memory
FFB	Flux Feedback
I/O	Input and Output
LCD	Liquid Crystal Display
LED	Light Emitting Diode
LSB	Least Significant Bit
PC	Phosphor-Coated
PCB	Printed Circuit Board

PIC	Peripheral Interface Controller
PID	Proportional Integral Derivative
PWM	Pulse Width Modulation
RAM	Random Access Memory
ROM	Read Only Memory
RC	Resistor-Capacitor
RGB	Red Green Blue
SSL	Solid State Lighting
TFF	Temperature Feed Forward
TIA	Transimpedance Amplifier
UART	Universal Asynchronous Receiver/Transmitter

LIST OF SYMBOLS

cd	Candela
µ	Micro
f	Frequency
F	Farad
Hz	Hertz
°	Degree
Ω	Ohm
Δ	Delta
λ	Lambda
τ	Time Constant
K	Kelvin
C	Celsius
ω	Omega
sr	Steradian

PUNCA CAHAYA DIOD PEMANCAR CAHAYA MERAH HIJAU BIRU MUDAH ALIH DENGAN MEKANISME KAWALAN WARNA UNTUK APLIKASI LAMPU BELAKANG

ABSTRAK

Tesis ini mengemukakan pembangunan mekanisme kawalan warna untuk sumber cahaya oleh Diod Pemancar Cahaya (LED) Merah Hijau dan Biru (RGB). Pencampuran secara penambahan daripada LED asas tersebut memerlukan mekanisme kawalan kerana warna yang dihasilkan tertakluk kepada variasi. Ini adalah disebabkan peningkatan suhu ambien dan pemanasan sendiri oleh LED tersebut. Titik warna akan berubah kerana penurunan keluaran keamatan sinaran tiap-tiap LED adalah tidak sama. Pengawal mikro dicadangkan sebagai unit pusat untuk mendapatkan set titik permulaan pencampuran warna seterusnya mengawal setiap LED apabila sisihan titik warna baru berubah melebihi had. Kaedah ini bergantung pada jangkaan voltan ke depan terhadap setiap LED dan sisihan ukuran sinaran oleh penderia optik. Mekanisme kawalan warna yang telah dibangunkan boleh mengekalkan gabungan titik warna dengan berkesan apabila tertakluk kepada ujian suhu ambien terpecut menerusi penenggelam haba yang dilekatkan pada LED. Sistem ini diuji pada dua jenis LED RGB. Sistem ini berupaya untuk mengurangkan 83 % ralat relatif untuk LED jenis pertama dan 78.6 % ralat relatif untuk LED jenis kedua. Ralat relatif diperolehi semasa proses mengukur dengan mekanisme kawalan tertutup mengurangkan ralat sistem kawalan terbuka daripada set titik permulaannya. Gangguan cahaya ambien juga berjaya dihapuskan semasa penderia beroperasi.

A PORTABLE RGB LED LIGHT SOURCE WITH COLOR CONTROL MECHANISM FOR BACKLIGHTING APPLICATION

ABSTRACT

This thesis presents the development of color control mechanism for Red, Green and Blue (RGB) Light Emitting Diode (LED) light source. The additive mixing by the primary LED requires a control mechanism since a color produced is subjected to variation. This is due to the influenced of elevated ambient temperature and self-heating of the LEDs. The color point will vary because the individual LEDs output radiant intensity degradation is not the same. A microcontroller is proposed as a central unit to obtain an initial set point of the color mixing thus controlling each LED when the difference of new color point exceeded tolerance. The method relies on the forward voltage prediction to the individual LEDs and the radiant intensity measured by an optical sensor. The developed color control mechanism can effectively maintain the mixed color point when it is subjected to an accelerated ambient temperature test through heating the heat-sink attached to the LED. The system is tested on two types of RGB LED. The system is able to reduced 83% of relative error for the first type LED and 78.6 % of relative error for the second type LED. The relative error is obtained during the measuring process with the closed-loop control mechanism reducing the open-loop control system error from its initial set point. The ambient light disturbance is also successfully eliminated during the sensor in operation.

CHAPTER ONE

INTRODUCTION

1.1 Overview

Solid-State Lighting (SSL) devices such as a light emitting diode (LED) and an organic LED (OLED) have shown a great potential to enhance the performance of artificial lighting. LED light source has shown its significant economic benefit due to their lower operating condition and longer lifetime's service (Azevado et al., 2009). Thus, the LEDs are better in energy consumption compared to the other conventional light sources such as incandescent light bulb, halogen light bulb and most compact fluorescent light (CFL). Although the LED luminaires lag slightly behind fluorescent light luminaires, continuous innovation has shown competitive improvement in its efficacy (Bardsley et al., 2014).

Despite that the CFL shows a good light efficacy, it is not environmental friendly since mercury is added in the fabrication process and poses a danger to our environmental health. Hence, LED is a greener choice for lighting purposes (Kim and Schubert, 2008). Moreover, LED shows inherent controllability that their luminance can be controlled or dimmable compared to other conventional light sources. This SSL device also offers saturated colors, robustness and small size device (Jacobs, Jie and Hente, 2008). Other advantages of LEDs are they are anti-vibration and shock resistant devices (Bergh et al., 2001).

There are two methods to generate white light for general illumination for example by the phosphor coated (PC) white LED or by mixing the light output of red, green, and blue (RGB) LED. The PC white LED suffers from shorten lifetime because of phosphors deterioration and efficiency dropped caused by the Stoke-shift characteristic of the down conversion which a phosphor absorbs shorter wavelength energy and emits it at a longer wavelength (Zukauskas et al., 2002).

Theoretically, color mixing from RGB LED could provide better efficiency and enable color adjustability. At present, this method is most admirable feature for future LED lamps or other applications such as backlighting because of it individually controllable. In turns, various shade of white or color can be created by tuning the ratios of each RGB LED strings (Ying, Tang and Huang, 2006), (LED Color Characteristic, 2012). In order for the RGB LED light source to achieve reliable luminous output and color stability for its application, various color control feedback are applied (Deurenberg et al., 2005). The control system in return could stabilize the luminous and color output that are influenced by ambient temperature and also self-heating of the LEDs.

1.2 Problem Statement

In general, luminous output and wavelength of LEDs are affected by temperature changes, driving current and ageing. The changes in LEDs junction temperature will result in a degradation of lifetime, efficiency and its forward voltage (Manninen and Orrevetelainen, 2007). As for the RGB LED, it is subjected to different luminous output degradation rate of individual LED due to the self-heating and ambient temperature changes. Thus, it will impact on its color point (Chhajed et al., 2005). Therefore, it requires color control mechanism system that able to tune the electrical power of each RGB LED to regulate the luminous output and its color balance.

Since the optical sensor operates based on the input optical signal, the environment illuminant might affect the accuracy of the detected output. Thus, it is required to prevent the input optical signal from being affected by external environment so that be reliable and usable to mobile outdoor (Muthu and Gaines, 2003).

Most of the explored control techniques are dependent on the International Commission on Illumination (CIE) standard to express a color. However, every human interprets a color differently with their own perception. Because of that, there is not entirely necessary for a system to produce an accurate color. Therefore, the aim of this research is to develop an embedded control mechanism on an arbitrary color point input according to the user desire with using a simple microcontroller.

1.3 Objectives

This project is carried out for the following objectives:

i. To develop an embedded color control mechanism system to maintain color point within minimum accuracy of at least 20 LSB employing 10-bit ADC converter for portable application.
ii. To eliminate the effect of ambient light disturbance when sensing in operation.

1.4 Scope of Work

The scope of the project is to design and implement the control mechanism to regulate the radiant intensity output losses of RGB LED and maintain its color point.

1.5 Thesis Organization

Chapter 1 comprises of the overview of the project which introduce the feature and future of RGB LED lighting, problem statement, objectives, scope of the project and thesis organization.

Chapter 2 summarizes the literature review for the RGB LED light source and it's luminous and color output control system design. Several LED driving techniques will be explained in this chapter. Various type of color control feedback or mechanism used to stabilize the RGB LED color light output will be discussed. Some background on the RGB LED and its application is studied as well.

Chapter 3 reveals the methodology used for this project. The road map and flow chart of the design will be discussed within this chapter. This chapter will describe the proposed block diagram of the color control circuit, parameters involved in the design, closed-loop flowchart design for the source code implementation and hardware design. The hardware integration is described and implementation using the optical sensor and forward voltage prediction is explained. In addition, the mechanism source code implemented in C programming language is described.

Chapter 4 indicate the results and discussions. The ambient temperature test on the RGB LED light source will be analyzed. This result implies the design of the color control mechanism. All other practical results and analysis from each approach of the methodology are discussed.

Chapter 5 is the conclusion for the achievement of the objectives. Furthermore, this chapter includes a brief statement of successfulness and future work.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

In this chapter, some background on the RGB LED and its application is studied. The perception of color and additive color mixing by using the RGB LED is discussed. In addition, a review is done on the methods of driving and dimming the LED. The color control feedback techniques are studied and elaborated to gather the information in order to implement the control mechanism system.

2.2 RGB LED Application

RGB LED can provide white light sources with variable colour point in consideration of tunable white point, wider color gamut, faster response, longer lifetime, high dimming ratio and higher luminance efficacy make RGB LED suitable as a backlight for high end Liquid Crystal Displays (LCD) applications (Muthu et al., 2002), (Hsieh et al., 2009). The advantages of LCD are light weight, high resolution and good color performance. LCD used for a wide range of display applications in consumer products such as notebooks, PC monitors, televisions, cellular phones and multimedia products (Cho and Kwon, 2009), (Nam et al., 2009). As display size and resolution are increases, it is also fundamental to optimize display backlighting. Backlighting module is important to drive light source in LCD technologies in consideration of LCD display quality since LCDs are not self-luminance display devices (Liu et al., 2010).

For general lighting illumination purposes, RGB LED has shown an advantage over Phosphor-Coated (PC) white LED as its luminous output can be tuneable. It could provide different white color temperature such as cool white, warm white and can be set to other white light according to the user mood (Lim et al., 2006).

2.3 Color

Color is defined as perceptual results of light in the visible region of spectrum. The human eye is sensitive to a small frequency band, known as visible light, ranging from approximately 390 nm to 720 nm. Human eye perceives certain color corresponding to certain wavelength within the electromagnetic spectrum. For instances, human will interpret visible light of the largest wavelength as red while that of smallest wavelength as blue, other colors will be interpreted according to their corresponding wavelength as shown in Table 2.1.

Table 2.1: Wavelength of distinct colors (Schubert, 2006)

Color	**Wavelength (nm)**	**Color**	**Wavelength (nm)**
Ultraviolet	< 390	Yellow	570 – 600
Violet	390 – 455	Amber	590 – 600
Blue	455 – 490	Orange	600 – 625
Cyan	490 – 515	Red	625 – 720
Green	515 – 570	Infrared	> 720

The radiometry is the detection and measurement of electromagnetic radiation across the total spectrum. Some terms used in the radiometric measurement such as the radiant power, radiant intensity, irradiance and radiance. The radiant power is radiant energy emitted over a surface in unit time interval. For the radiant intensity, it is defined as a result of the radiant power emitted by a source in an extremely small solid angle. The irradiance is a result of radiant power incident on a surface, whereas the radiance is a measure of radiant power at the receiver (Wyszecki and Stiles, 1982).

Figure 2.1 depicts the illustration of solid angle of the electromagnetic radiation. As depicted, the solid angle cuts off an area on the surface of a sphere, *S* centered at *C* and radius of *r*. The solid angle size is obtained by

$$\omega = \frac{S}{r^2} \tag{2.1}$$

The measurement unit of solid angle is in steradian unit denoted as *sr*.

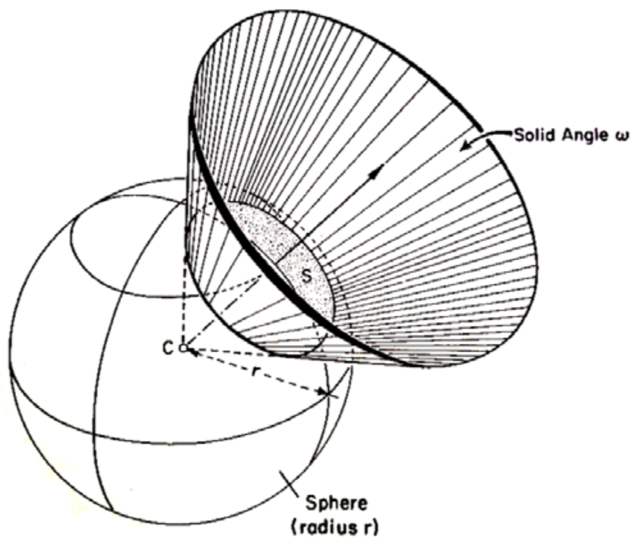

Figure 2.1: Illustration of electromagnetic radiation solid angle (Wyszecki and Stiles, 1982)

On the other hand, photometry is a radiometric power that is scaled by the spectral response of the human eye. Photometry is most likely equivalent to radiometry except the measurement is within the visible wavelength range. Table 2.2 lists some units of measurement of the radiometric and photometric in comparison.