An Optical Feedback System for 2D Dimming RGB LED Backlight

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Abstract

For several years, many researchers have proposed LED backlight dimming technology for low power consumption and high contrast ratio. One of the major issues plaguing RGB LED with 2D dimming technology is color shift. This undesirable variation makes it difficult to use RGB LED as light sources in the backlight system. This paper describes the useful method of the optical feedback system for 2D dimming RGB LED backlight. The test results show that our proposed method is very suitable for the 2D dimming technology.

1. Introduction

As the LCD market is becoming larger, backlights for LCD TVs are more important because those are directly related to the LCD TV image quality such as contrast ratio, color gamut and power consumption, etc [1]. The 2D dimming technology is one of the best solutions for high picture quality and low power consumption [2-5]. When white LEDs are used in the 2D dimming backlight system, there is no need an optical feedback system because white LED makes white light source by itself. However, in the case of using the RGB LED, the color stability for white balance is the main technical issue because Red, Green, and Blue LED have thermal and long-term time dependencies [6]. Light crosstalk is another problem for minimizing color deviation. It will be appeared when the backlight is locally dimmed in the top emitting optic structure and there has no optical isolators for protecting light crosstalk among neighboring zones. To overcome these problems, we proposed the optical feedback system for 2D dimming and verified the effectiveness of our system with the 47-inch RGB LED backlight for large size LCD TV.

2. Color feedback control

Table 1 shows the color coordinate and luminance of the LCD module with open loop control during the aging time (0 to 120-minute). The measured results show that color variation $(\Delta u^{'}v^{'})$ is 0.016 and luminance degradation (ΔL) is 64 nits. In application such as LCD backlighting, where the light sources are viewed directly, this variation may be unacceptable in high-end application.

TABLE 1. The measured data of color coordinate and luminance with open loop control (@ Room temperature, Aging time = 120min, Full white)

Time [min.]	u’	v’	Luminance [nits]
0	0.1905	0.4610	625
10	0.1865	0.4568	601
20	0.1844	0.4540	588
30	0.1832	0.4522	579
40	0.1824	0.4510	573
50	0.1819	0.4502	569
60	0.1815	0.4496	566
70	0.1813	0.4492	565
80	0.1811	0.4488	563
90	0.1810	0.4485	562
100	0.1810	0.4485	562
110	0.1810	0.4484	561
120	0.1809	0.4483	561

To minimize these unwanted phenomena, we proposed the useful optical feedback system depicted in Figure 1.

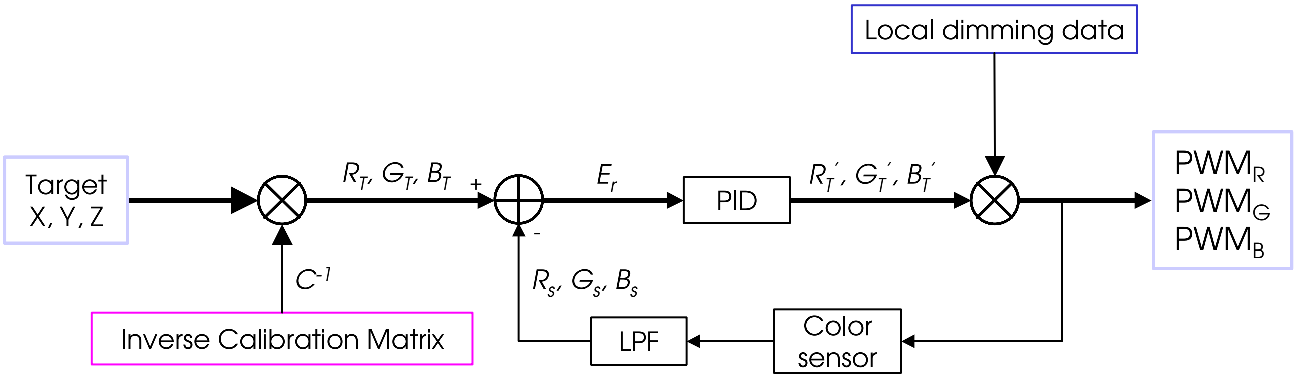

Fig. 1. Proposed optical feedback system for 2D dimming.

The optical feedback system maintains the white point color coordinate. For the operation of color feedback control, we must derive the calibration matrix. The procedures of measuring tri-stimulus values for generating calibration matrix is below:

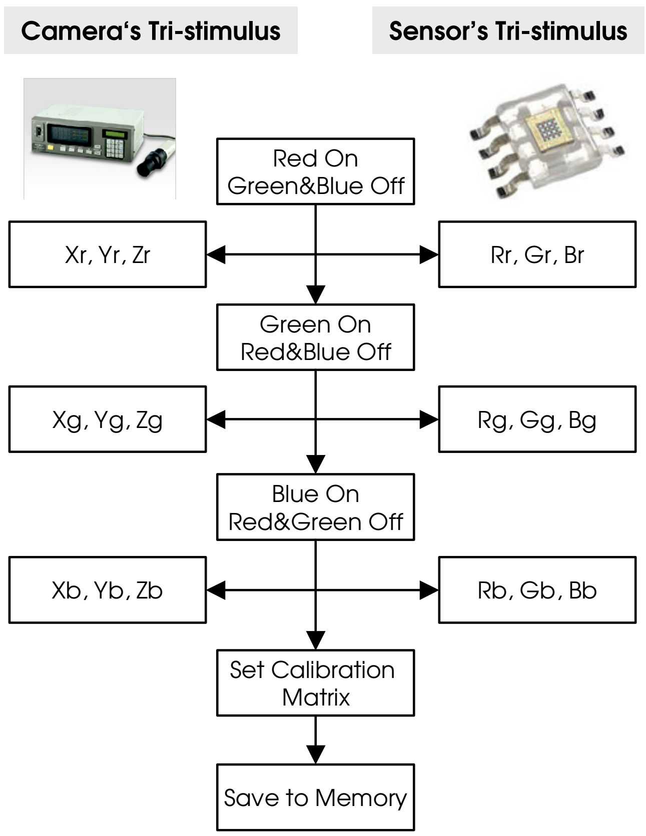

Fig. 2. The procedures of color sensor's calibration in RGB LED backlight system.

Deriving calibration matrix is depicted in Figure 2 as a Set Calibration Matrix process. From the measured data, camera's tri-stimulus values are can be expressed by equation (1).

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = \begin{bmatrix} X_r & X_g & X_b \\ Y_r & Y_g & Y_b \\ Z_r & Z_g & Z_b \end{bmatrix} \begin{bmatrix} r \\ g \\ b \end{bmatrix} \qquad (1)$$

where (X_r, Y_r, Z_r) are the measured XYZ tri-stimulus values when only Red LED is on, (X_g, Y_g, Z_g) are the measured XYZ tri-stimulus values when only Green LED is on, and (X_b, Y_b, Z_b) are the measured XYZ tri-stimulus values when only Blue LED is on.

And also color sensor's tri-stimulus values are expressed by equation (2).

$$\begin{bmatrix} R \\ G \\ B \end{bmatrix} = \begin{bmatrix} R_r & R_g & R_b \\ G_r & G_g & G_b \\ B_r & B_g & B_b \end{bmatrix} \begin{bmatrix} r \\ g \\ b \end{bmatrix} \qquad (2)$$

where (R_r, G_r, B_r) are respective RGB channels of the color sensor when only Red LED is on, (R_g, G_g, B_g) are the respective RGB channels of the color sensor when only Green LED is on, and (R_b, G_b, B_b) are the respective RGB channels of the color sensor when only Blue LED is on.

In order to calibrate sensing values between camera and color sensor, equation (1) and (2) are can be replaced by equation (3).

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = \begin{bmatrix} X_r & X_g & X_b \\ Y_r & Y_g & Y_b \\ Z_r & Z_g & Z_b \end{bmatrix} \begin{bmatrix} R_r & R_g & R_b \\ G_r & G_g & G_b \\ B_r & B_g & B_b \end{bmatrix}^{-1} \begin{bmatrix} R \\ G \\ B \end{bmatrix} = [C] \begin{bmatrix} R \\ G \\ B \end{bmatrix} \quad (3)$$

where C is calibration matrix and can be defined by equation (4).

$$[C] = \begin{bmatrix} X_r & X_g & X_b \\ Y_r & Y_g & Y_b \\ Z_r & Z_g & Z_b \end{bmatrix} \begin{bmatrix} R_r & R_g & R_b \\ G_r & G_g & G_b \\ B_r & B_g & B_b \end{bmatrix}^{-1} \quad (4)$$

The operation of our feedback system is composed of five steps:

Step 1 : Set the target tri-stimulus values $[X, Y, Z]$.

Step 2 : Get the target values $[R_T, G_T, B_T]$ by multiplying tri-stimulus values $[X, Y, Z]$ with inverse calibration values $[C^{-1}]$.

Step 3 : Compares the target values $[R_T, G_T, B_T]$ with sensed values $[R_S, G_S, B_S]$, which are feedback signal from sensors. Period of the sensing time, the low pass filter is used to eliminate the high frequency noises.

Step 4 : A proportional integral derivative (PID) system is utilized for the stable closed loop feedback control. This system can neither be sluggish to reach the target, nor overcompensate with an overshoot in correction.

Step 5 : We can get the PWM driving waveforms for the LED driver by multiplying zone values by the outputs of PID system.

3. System architecture

Figure 3 shows the circuit block diagram of our proposed backlight system that is composed of mainly three modules (Control board, LED driver and Calibration system). The main functions are described as following briefly:

- Control board: Generate control signals to the panel and local dimming values to the LED driver.
- LED driver: Supply the Pulse Width Modulated (PWM) currents to the LED packages and performs closed loop control for the color stability.
- Calibration system: Calibrate sensing values between camera and sensor and set the color and luminance uniformity.

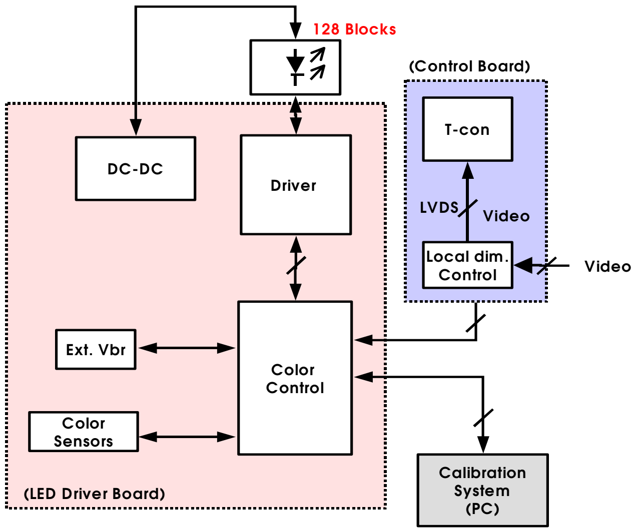

Fig. 3. The circuit block diagram of the RGB LED backlight system.

4. Results and discussion

Figure 4 shows the measured data of the color variation from initial state (time=0) to aging state (time=120 min) with the room temperature. The color drift is 0.0086 and luminance degradation is 35.3 nits during the aging time. This result is meaningful when compared with open loop control (0.0016 / 64 nits).

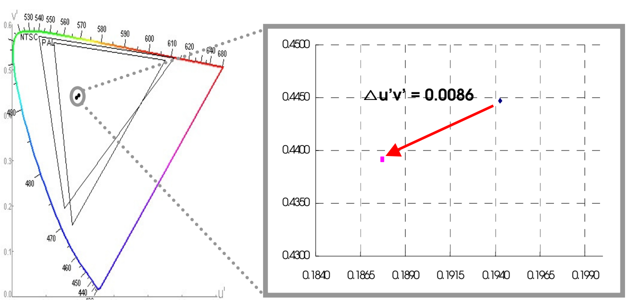

Fig. 4. Color drift on the operation of the optical feedback system (@Temp 25℃, Aging time=120min, Full white).

The system specifications and experimental results are summarized in Table 2. From these results, we are sure to say that all specification such as luminance, power consumption, color gamut, and color drift are satisfied and our proposed system works as well as expected.

TABLE 2. The experimental results of a 47-inch RGB LED LCD TV

Item	Specification	Results
Luminance [nit]	550	560
Color temperature [K]	10,000	9,825
Color Drift	$\triangle$u'v' < 0.01 (@Center)	0.0086
Color Uniformity	$\triangle$u'v' < 0.008	0.004
Color Gamut [%]	105	106
Power Consumption [W]	260	230
MPRT [ms]	6	6
DCR	300,000:1	300,000:1

The displayed image and its corresponding image of backlight are shown in Figure 5.

5. Summary

The color feedback control method is core technology for RGB LED 2D dimming scheme because there exist light interference among neighboring zones and RGB LED has thermal and long-term time dependency. To solve these problems, we proposed an optical feedback control system and verified the effectiveness of our method with 47-inch LCD module.

6. References

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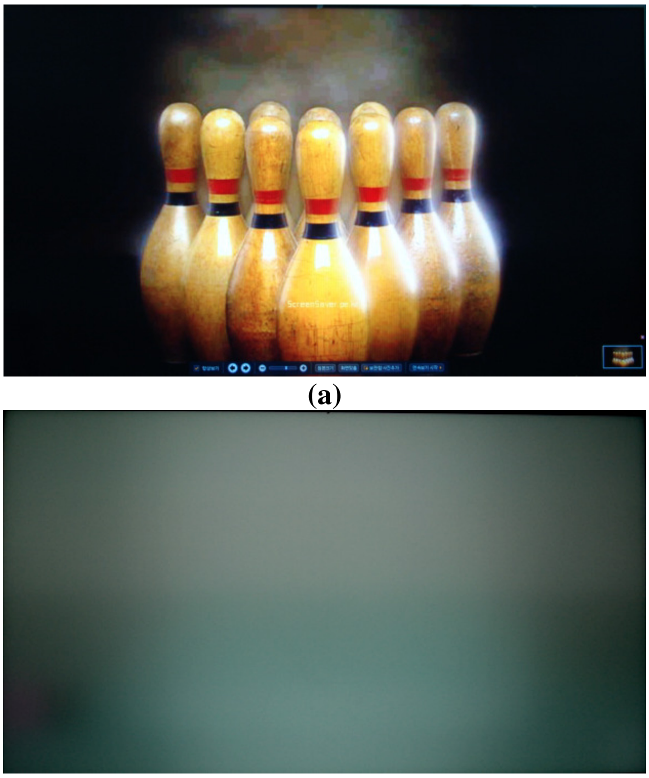

(a)

(b)

Fig. 5. The output images of our designed LCD module: (a) Panel (b) Backlight.