An X-Y Channel Dimming LED Backlight with Temperature Compensation for LCD TVs

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Abstract

In this paper, an X-Y channel dimming light emitting diode (LED) backlight with temperature compensation for in LCD TVs is proposed. It shows local dimming effects such as reduced power consumption and high dynamic contrast ratio even with much less number of LED drivers than that of the conventional two-dimensional local dimming method. Moreover, the image distortion caused by temperature variation of LED block can be effectively compensated. The validity of the proposed dimming method is verified by simulation and experimental results based on a RGB-LED backlight of a 32-inch LCD TV.

1. Introduction

Liquid-crystal-display (LCD) is one of the most popular display devices since it has many advantages such as high resolution, low power consumption, light weight, slim size and so on. When looking into an LCD used in monitor or TV applications, a backlight unit (BLU) is usually required. The BLU supplies light to the LCD panel and consumes the most power. The conventional backlight of LCDs illuminates at full luminance regardless of the displayed images, resulting unnecessary power consumption and low contrast ratio due to light leakage in the dark state.

To reduce power consumption and enhance the image contrast ratio of a LCD backlight, several techniques [1]-[10] in relation with adaptive dimming control such as 0-D (uniform dimming or backlight scaling), 1-D (line or channel dimming), and 2-D (block or cluster dimming) methods. In the backlight scaling method [1]-[3], the entire backlight luminance is reduced by a dimming factor $k$, and at the same time, the transmittance of liquid crystal (LC) is enhanced by a factor $1/k$, according to the input video signal. To reduce the power consumption more effectively, local (channel or block) dimming methods [4]-[9] have been suggested. In these methods, the backlight is divided into local areas (channels or blocks) and backlight scaling method is applied to each local area. The 2-D block dimming method is the best way to reduce power consumption and enhance image contrast ratio. However, it increases the number of drivers to control the luminance of each division block.

On the other hand, the luminance levels of the LED backlight are not stable over temperature and time due to the inherent characteristics of the LED [10]. In order to minimize luminance variation over temperature and time, optical feedback system is a good solution [10]. However, it is difficult to compensate the luminance difference between each LED module. The luminance variation rate between upper and lower part of LED backlight is different because the temperature of upper part of LED backlight is normally higher than that of lower’s. Especially, in case of the local dimming LED backlight, the luminance variation rate of each LED blocks is different due to the different temperature variation of each LED block. Therefore, temperature compensated is needed to prevent the image from being distorted.

To solve these problems, a new adaptive dimming X-Y channel LED backlight system with temperature compensation for LCD TVs is proposed. As shown in Fig. 1, the proposed LED backlight utilizes channel switches to control the luminance of individual division screen and a resistor to sense the current of each LED blocks. By using the proposed technique, low power consumption as well as high contrast ratio is successfully obtained with less number of drivers than that of conventional local dimming method. Moreover, the luminance variation of each LED blocks caused by temperature variation is effectively compensated. In this paper, the characteristics of LED backlight are investigated and a new adaptive dimming algorithm as well as the temperature compensation methods is proposed for the X-Y channel LED backlight.

2. Proposed LED Backlight System

2.1 Operational Principle

The proposed LED backlight system as shown in Fig. 1 consists of LED modules which have series connected LEDs. These LED modules are connected to each other in a matrix structure with row channels (X channels) and column channels (Y channels). To control each channel, row and column switches are connected at the end of each channel and to an external power source. Therefore, the brightness of each division block can be controlled by a certain combination of row and column switches. The resistor, $R_s$, and switch, $S_{rs}$, are for sensing current of each LED module. The current values sensed by sensing resistor, $R_s$, are used to compensate luminance variation caused by temperature of each LED blocks.

The operation period is composed of sensing and pulse width modulation (PWM) dimming parts as shown in Fig. 2. The current of each LED module can be sensed during the sensing period, and the luminance of each block can be decided during the PWM dimming period. Since the sensing period is much smaller than the PWM dimming period, the luminance of each block affected by
the sensing period can be neglected. During the sensing period, the switch, \( S_{\\text{row}} \), is turned off, and row switches are turn on and off. During one of row switches, \( S_{\text{row},m} \) is turned on, the column switches are turned on and off one after the other. Therefore, only one LED block is turned on for an instant and its current can be sensed by a resistor, \( R_s \).

The proposed adaptive dimming method can be operated in three modes; row channel, column channel and row-column (X-Y) channel dimming mode. Fig. 3 shows the backlight brightness patterns in each mode. In the row channel dimming mode, the row switches are PWM switching while column switches are turned on resulting row channel dimming backlight image as shown in Fig. 3 (a). In the column channel dimming mode, the column switches are PWM switching while row switches are turned on resulting column channel dimming backlight image as shown in Fig. 3 (b). In the X-Y channel dimming mode, the row and column switches are operating in PWM simultaneously as shown in Fig. 2. In this mode, the backlight brightness as shown in Fig. 3 (c) is decided by logical ‘AND’ operation between row and column switches because LED module of each division block, \( B_{\text{row},m,n} \) is turned on when both row and column switches, \( S_{\text{row},m,n} \) and \( S_{\text{col},m,n} \) are turned on. Therefore, the proposed dimming method results in \((M+N) \) drivers as opposed to \((M\times N) \) drivers of conventional block dimming method.

### 2.1 Dimming Algorithm

A new adaptive dimming algorithm is needed to decide the luminance of each division block for the proposed LED backlight system. The proposed dimming algorithm is composed of three major procedures; finding the maximum level data (MLD) from source image corresponding to each division block of LED backlight, selecting the brightness level of each division, and modifying the image information to preserve the source image.

Fig. 4 shows the source image and its maximum level data (MLD) of each block, \( MLD \), which is a \( M \times \times N \) vector-matrix. From MLD, its maximum row and column MLDs, \( MLD_{\text{row},m} \) and \( MLD_{\text{col},n} \), can be decided as shown in Fig. 4 (b).

From gamma curve and \( MLD_{\text{row},m} \) and \( MLD_{\text{col},n} \), the duty ratio of each row and column switches can be determined and expressed as equations (1) and (2), as follows

\[
D_{\text{row},m} = \left[ \frac{MLD_{\text{row},m}}{255} \right],
\]

\[
D_{\text{col},n} = \left[ \frac{MLD_{\text{col},n}}{255} \right].
\]

Then, the dimming factor of each block, \( k_{\text{row},m,n} \) can be decided by the minimum value of \( D_{\text{row},m} \) and \( D_{\text{col},n} \) and can be expressed as in equation (3).

\[
k_{\text{row},m,n} = \min(D_{\text{row},m},D_{\text{col},n})
\]

From this equation, theoretical power reduction rate compared to the conventional LCD system can be expressed as

\[
\text{Power Reduction Rate} = 1 - \sum_{m=1}^{M} \sum_{n=1}^{N} k_{\text{row},m,n} / (M \times N)
\]

As shown in Fig. 5, the gray level data of backlight luminance, \( BLD \), which is a \( M \times N \) matrix after adaptive dimming. Here, the gray level data of each block luminance, \( BLD_{\text{row},m,n} \), can be expressed as

\[
BLD_{\text{row},m,n} = 255 \times k_{\text{row},m,n}^{1/\gamma}
\]

For the perceived image after backlight dimming to be identical to that of the original source image without backlight dimming, the code value of the source image, \( c_{\text{row},m,n} \), corresponding to each division block, \( B_{\text{row},m,n} \) of the backlight should be enhanced as

\[
v_{\text{row},m,n}^{*} = \frac{c_{\text{row},m,n}}{k_{\text{row},m,n}^\gamma}
\]

### 3. Temperature Compensation Method

#### 3.1 Characteristics of Implemented LED Backlight

The proposed adaptive dimming method is adapted for a 32-inch LCD TV. The RGB-LEDs are used as the backlight source and the backlight is divided into 5 by 5 blocks as shown in Fig. 6 (a). Each LED block has 20 RGB-LED clusters which comprises 1 red, 2 greens and 1 blue small size LEDs. To drive the LEDs, 30 drivers as shown in fig. 6 (b) are used. Note that 75 drivers are needed in the conventional block dimming method. The three power sources for red, green and blue LED strings are used.

To compensate the luminance variation due to the change of temperature, the luminance-current characteristic with a constant voltage is investigated as shown in Fig. 7. In this figure, point \( A \) refers to normal temperature, \( T_L \) and point \( B \) refers to saturated temperature, \( T_F \). As can be seen in this figure, the LED luminance can be a linear function of LED current when a constant voltage is supplied. Therefore, the luminance of each block can be expected by measuring the current of each LED block and expressed as

\[
L_{\text{row},m,n} = \alpha \cdot i_{\text{row},m,n} + \beta
\]
where \( \alpha = M \times N \frac{L_i - L_{i+1}}{L_i - L_1} \) and \( \beta = \frac{i \cdot L_1 - i \cdot L_i}{L_i - L_1} \).

Therefore, the luminance variation ratio between normal and high temperature, \( k_{t,n} \), can be expressed as

\[
k_{t,n} = \frac{L_i}{L_i + \Delta L} = \frac{\alpha \cdot (i \Delta t) + \beta}{\alpha \cdot (i + \Delta i) + \beta} \quad (8)
\]

Here, \( i \Delta t \) can be decided by a reference value, and \( \Delta i \) can be measured by sensing resistor, \( R_o \) in Fig. 1. and 2. From the temperature compensation factor, \( k_{t,n} \), it is expected that the luminance of \( B_{t,n} \) is enhanced by a factor, \( 1/k_{t,n} \).

### 3.2 Temperature Compensation Methods

There are two methods to compensate backlight luminance from temperature variation. One is to compensate backlight luminance by adjusting duties of row and column switches from equations (1) and (2), and the other is to compensate the image, \( cv \), from equation (6).

#### 3.1.1 Backlight luminance compensation method

From the temperature compensation factor, \( k_{t,n} \), the maximum temperature compensation factors of each row and column channels, \( k_{t,n}^{\text{row}} \) and \( k_{t,n}^{\text{col}} \) can be obtained. Then, temperature compensated MLDs can be expressed as

\[
\text{MLD}_{\text{row, max}} = \text{max}(MLD_{1,n}^{\text{row}} \times k_{t,n}^{\text{row}}), \text{MLD}_{2,n}^{\text{row}} \times k_{t,n}^{\text{row}}), \ldots
\]

\[
\text{MLD}_{\text{col, max}} = \text{max}(MLD_{i,n}^{\text{col}} \times k_{t,n}^{\text{col}}), \text{MLD}_{i+1,n}^{\text{col}} \times k_{t,n}^{\text{col}}), \ldots
\]

Then, the dimming factor of each block, \( k_{n} \), of equation (3) can be corrected to equation (11).

\[
k_{n} = \min(D_{\text{row, max}}, D_{\text{col, max}})/k_{t,n} \quad (10)
\]

#### 3.1.2 Backlight luminance compensation method

From equation (5), the total luminance distribution of backlight resulting from temperature variation can be expressed as

\[
BL_{\text{kt}}(x,y) = \sum_{n=1}^{N} \sum_{i=1}^{M} k_{n,i} \times BL_{n,i}(x,y) \quad (11)
\]

Therefore, from equation (3), equation (4) can be corrected to

\[
\[cv_{\text{kt}}(x,y) = cv(x,y) \times \frac{1}{BL_{\text{kt}}(x,y)^{1/\gamma}} \quad (12)
\]

### 4. Experimental Results and Concluding Remarks

Fig. 8 (a) and (b) are the panel images at normal temperature and saturated temperature of 30 minutes later, respectively. Fig. 8 (b) becomes brighter than Fig. 8 (a). Fig. 8 (c) and (d) are compensated images from distortion image of Fig. 8 (b), using backlight luminance compensation method and image processing compensation method, respectively. These two compensated images look similar to the image of Fig. 8 (a). To make sure the validity of the proposed temperature compensation methods, the green color levels of panel images as shown in Fig. 8 at \( x = 680 \) pixels are plotted in Fig. 9. From this figure, the luminance variation by temperature can be well compensated by the proposed compensation method.

A novel X-Y channel dimming method with temperature compensation for LED backlight system in LCD TVs is proposed.