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Backlight Local Dimming Algorithm for High Contrast LCD-TV

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Abstract: *A backlight local dimming algorithm is proposed to achieve high static contrast more than 10000:1 on the LCD-TV which is mounted by an LED-array backlight. On the dark region of the image, the backlight is dimmed to reduce light leakage and get deep dark. The proposed algorithm can avoid or significantly reduce such annoying local dimming artifacts as luminance decrease, nonuniformity and screen flicker in displaying video sequences.*

Keywords: Local dimming; Contrast; Light leakage; LED; LCD.

Introduction

Conventional LCD (Liquid Crystal Display) panel is composed by a constant and uniform backlight and a TFT-LCD. The backlight supplies constant light source and LC cells on the TFT-LCD work as switches controlling the brightness of correspondent pixels. This architecture suffers from the light leakage of LC cells. Light leakage means that light can not be obstructed fully even if the LC switch is turn off. That is, the pixel looks not full black even if the pixel value is zero. Other very dark gray levels also do not appear dark enough because of light leakage. Light leakage problem depresses the LCD-TV contrast greatly. The brightness of the light leakage is about 0.5 nits with a peak white of 500 nits in general LCD-TV. That is, the contrast is only about 1000:1. New technology is desired to reduce the light leakage for achieving high contrast on LCD-TV.

When referring to the contrast of LCD-TV, the difference of dynamic contrast and static contrast should be differentiated. Dynamic contrast means the contrast between the maximal pixel brightness in one frame and the minimal pixel brightness in the same frame or any other frame. Static contrast means the contrast between the maximal and minimal pixel brightness in the same frame. It is more difficult to improve the static contrast than dynamic contrast. In this paper, it always means static contrast when we refer to the item "contrast".

The pixel brightness of LCD perceived by the user is the product of the backlight luminous intensity and the panel transmittance. So, two ways can be followed to reduce the light leakage. First one is to improve the architecture of LC cell to reduce the transmittance of dark pixels. The pace on this way is small until now. Another way is to dim the backlight on dark image region. The relation between backlight luminous intensity and perceived luminance of LCD panel is almost linear. So, smaller backlight luminous intensity leads to less light leakage. This paper is focused on the backlight dimming method to reduce the light leakage and increase the contrast of LCD-TV.

Some efforts have been done to reduce the light leakage and improve the contrast by dimming backlight. Adaptive Brightness Intensifier method [1] dims the backlight luminous intensity uniformly by some factor k and compensates the image signals by the inversed factor $1/k$ to keep invariant pixel brightness. This uniform backlight dimming method can reduce some light leakage, but it is too conservative in reducing light leakage since the factor k is greatly limited by the bright image region. Too large factor k may lead to overflow of pixel value when compensating image signal. The potential of larger k and more light leakage reduction can be mined by vertically isolating backlight lamps into several groups using some isolators and adopting different factors k for each lamp group [2]. However, this method may suffer from less backlight uniformity in each group and blocking artifacts around the boundary of two neighbor groups because of isolators. Moreover, both of these published methods are mainly focused on static images. Video is a more rigorous case for backlight dimming.

We developed a backlight local dimming system to reduce the light leakage on dark image region, and achieve high static contrast when display videos on LCD-TV. The backlight is grouped into blocks and the intensities of those blocks in dark image region are dimmed to reduce the light leakage and get deep darkness. This paper describes the backlight local dimming algorithm in detail. The proposed dimming algorithm can achieve contrast more than 10000:1, and avoid annoying visual artifacts even when displaying rigorous video scene. In the second section of this paper, the structure of backlight local dimming and the artifacts may occur on local dimming are explained. The details of the proposed dimming algorithm are described on the third section. The fourth section demonstrates some test results of the proposed system.

Backlight local dimming system

Backlight dimming can be implemented by some backlight luminous intensity control circuits, which is economical and practical. Several kinds of backlight dimming technology have been developed to improve the image quality and power efficiency of LCD-TV. Backlight global dimming method dims the whole backlight by a universal factor in each frame, Figure 1(a). This method is mainly used to reduce power consumption [1] or improve dynamic contrast. Backlight local dimming method dims the different regions of the backlight by different factors according to the image

contents of correspondent regions, Figure 1(b). In high dynamic range display domain, a display system with
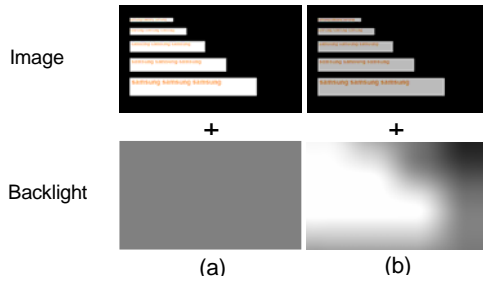

Figure 1. Global dimming and local dimming
(a) Global dimming   (b) Local dimming

locally dimming LED backlight has been developed to display high contrast images [3]. Their source signal is high dynamic range image, and the driving cost is very high since each LED element is controlled independently.

We developed a high contrast LCD-TV whose backlight can be dimmed locally according to the image contents. RGB-LED array is adopted for the backlight. RGB-LED has wide color gamut, fast response time and linear luminance control to PWM (Pulse Width Modulation) percentage, and LED elements can be grouped into blocks conveniently. The LED array is grouped into some rectangular blocks, Figure 2. Corresponding to the LED blocks, the image is also divided into some non-overlapped block regions. The luminous intensity of each LED block is calculated basically according to the corresponding image block. The LED luminous intensity is dimmed only on dark image blocks and kept to the peak value on the bright image blocks, because light leakage amount is small compared with peak white luminance and light leakage affects the image quality mainly on dark image region. RGB channels are dimmed simultaneously by same ratio.

Local dimming method has more flexible control to the backlight and can get much more static contrast improvement than global dimming method. However, there are several critical problems for local dimming which should be dealt with modestly. These problems may lead to serious visual artifacts of image quality if local dimming algorithm is not designed skillfully.

First critical problem of local dimming is how to decide the luminous intensity of each LED block according to the image contents. The most naïve method is to calculate the LED luminous intensity based on the average gray level of each image block. This method may lead to serious brightness decrease artifact. As an example, considering the scene of night sky with some bright starts, the average gray level of the scene is very dark. If the backlight intensity is set to be very small, the bright stars may look too dark. If the LED luminous intensity is decided by the maximal gray level of each image block, it is too sensitive to noise. Some tradeoff algorithm is required to balance the majority and maximal gray levels in each image block.

Another latent problem of local dimming is the nonuniformity artifact. In the local dimming system, each
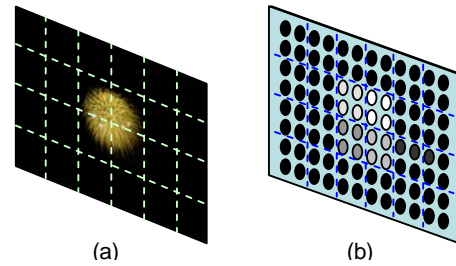

Figure 2. Local dimming system
(a) Image blocks   (b) LED blocks

LED block is controlled independently. The diffuser between backlight and TFT-LCD provides smooth light field and avoids blocking artifact between two LED blocks, but the smoothed light field may cause nonuniformity. For example, there is one white block on black background in the image. The pixel values are same inside this white block, but their brightness are different because the backlight is not uniform. The edge of the white block may look much darker than the center of the block. Figure 3 illustrates a 1D example of the nonuniformity. General linear low-pass filter can be implemented spatially to the LED intensities to get smoother light field and alleviate the nonuniformity artifact, but the brightness on bright region may also be decreased and the contrast is reduced.

Another annoying artifact may caused by local dimming is screen flicker. When image contents of the video sequence change or move very quickly and frequently, the calculated LED luminous intensities may also change very quickly and frequently. Frequent backlight change brings the potential trouble of screen flicker. When backlight intensity changes more than pixel values do, the flicker artifact will be more obvious. In our local dimming system, each LED block illuminates not only the correspondent image block but also other image blocks because of the light diffuser and reflector structure inside the LCD panel, though the luminous intensity of

each LED block is calculated mainly from the correspondent image block. When only part of the image changes quickly in temporal and other parts are static, the
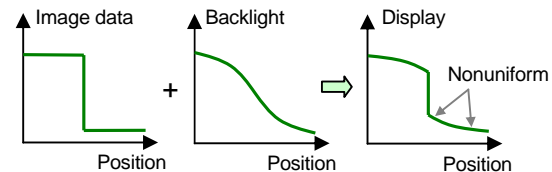

Figure 3. Nonuniformity problem

LED luminous intensity of the changeable image region may change roughly. After light spreads to the static image regions, the flicker artifacts will be very obvious in those static regions.
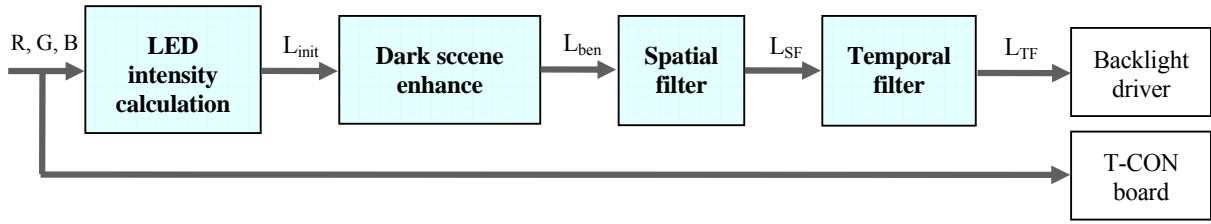
R, G, B → **LED intensity calculation** → L_{init} → **Dark scene enhance** → L_{ben} → **Spatial filter** → L_{SF} → **Temporal filter** → L_{TF} → Backlight driver

→ T-CON board

Figure 4. Structure of the local dimming algorithm

Local dimming algorithm

In our developed LCD-TV system, a backlight local dimming algorithm is designed skillfully to get high contrast and avoid the annoying local dimming artifacts mentioned before. The proposed algorithm includes four parts working serially, shown as Figure 4. They are LED intensity calculation, dark scene enhance, spatial filter and temporal filter to the LED luminous intensities.

In the LED intensity calculation part, weighted average of the histogram of each image block is calculated to decide the initial luminous intensity of correspondent LED block, shown as follow.

$$L_{init}(n) = \min\left(L_{MAX}, \frac{T_L}{P_{NUM}}\sum_{i=0}^{255}(H_n(i)\cdot W(i))\right) \quad (1)$$

where $L_{init}(n)$ is the initial luminous intensity of nth LED block, L_{MAX} is the allowable maximal LED luminous intensity level, T_L is a predefined parameter used to control the local dimming degree, P_{NUM} is the total pixel number in n^{th} image block, $H_n(i)$ is the histogram of nth image block, and $W(i)$ is a predefined weight vector. For brighter pixel value, larger weight $W(i)$ is defined. By this method, the major gray levels, small bright objects and noise pixels of each image block can be balanced when calculating LED intensity. In this paper, 64 levels are defined for LED intensity. That is, L_{MAX} equals to 63. Moreover, only luminance channel is considered when calculating histogram $H_n(i)$ for simplification.

In the dark scene enhance part, initial LED luminous intensities are enhanced in case of very dark scene. If there are some objects in very dark scene, these objects may appear very dark because the average intensity of the backlight is very dark after local dimming. In the proposed algorithm, those LED intensities above average intensity are enhanced to improve the brightness of the objects on dark background and increase contrast. The enhance method can be described as follow.

$$L_{ben} = \begin{cases} L_{init} & \text{if } (L_{init} < L_{mean}) \ or \ (L_{mean} > T_M) \\ \min(L_{MAX}, L_{init} + T_B \cdot (L_{init} - L_{mean})) & \text{else} \end{cases} \quad (2)$$

L_{ben} is the enhanced LED luminous intensity, L_{mean} is the mean value of all L_{init} in current image, T_M is a threshold used to define dark scene, and T_B is a predefined parameter used to control the enhancement degree.

In the spatial filter part, a non-linear low-pass filter on LED brightness values is proposed to reduce the nonuniformity artifact. General low-pass filter, such as Gaussian LPF, can also smooth the light field and reduce

nonuniformity artifact but the brightness of objects may also be reduced by this kind of linear low-pass filter when there is only a few bright LED blocks on dark background, shown as Figure 5(b). The proposed non-linear filter is designed as follow.

$$L_{SF}(n) = \max(L_{ben}(n), \{L_{ben}(m) - T_{SF} \mid m \in \Phi(n)\}) \quad (3)$$

where $L_{SF}(n)$ is the spatial filter output of the luminous intensity of nth LED block, T_{SF} is a predefined parameter used to control the smoothness of the filter, and $\Phi(n)$ is a neighbor region centered at n^{th} block with the size of 3×3. This non-linear low-pass filter can keep the intensity of each LED block quite well, shown as Figure 5(c).

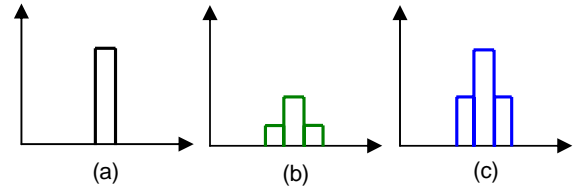In the temporal filter part, a scene adaptive IIR temporal

(a)   (b)   (c)

Figure 5. Low-pass filter on LED intensities

filter is implemented to the LED intensities to smooth temporal backlight changing and eliminate screen flicker artifact. The IIR filter is designed basically as follow.

$$L_{TF}^{(k)}(n) = R \cdot L_{SF}^{(k)}(n) + (1 - R) \cdot L_{TF}^{(k-1)}(n) \quad (4)$$

where $L_{TF}(n)$ is the output of temporal filter, (k) and (k-1) indicates the current and previous frame, and R ($0 < R \leq 1$) is the parameter controlling the smoothness of the IIR low-pass filter. The smaller the R is, the smoother the IIR filter is and the less flicker is observed. But too small R leads to the lagging of backlight changing behind the image signal changing, especially in case of sudden scene changing. In the proposed adaptive temporal filter, R is decided adaptively according to the video content, shown as follow.

$$R = \min\left(1, \ T_{TF} + \left|P_{mean}^{(k)} - P_{mean}^{(k-1)}\right|\right) \quad (5)$$

where T_{TF} is a predefined parameter used to control the shape of IIR filter, P_{mean} is the normalized mean pixel value of the whole image, and (k) and (k-1) indicates the current and previous frame. By the adaptive IIR filter, the backlight changes rapidly when there is significant scene changing, and otherwise, the backlight changes smoothly and the scene flicker artifact is avoid.

Experimental results

We implemented the proposed algorithm on a FPGA chip and developed a 32inch LED LCD-TV whose backlight is controlled by the FPGA chip. 2160 RGB-LED elements are mounted under a Samsung TFT-LCD with a 1366×768 resolution and grouped into M×N blocks on the backlight. The proposed algorithm is compatible to various block number. In out test, 8×8 blocks are designed. Some thresholds and parameters used in tests are listed in Table 1. The weights $W(i)$ used in LED intensity calculation part are set as the square of gray level i.

Table 1. Thresholds and paramters

Parameter	T_L	T_M	T_B	T_{SF}	T_{TF}
Value	0.0625	5	3	20	0.125

Test patterns including static images, moving sequences and cable TV signals were tested on this TV set. Figure 6 illustrates six of the test patterns. In each test pattern, two test points are measured to evaluate the contrast, one point in bright region and another one in dark region, shown as the gray dots in Figure 6. Figure 7 shows the contrasts of the six test patterns in Figure 6, where the broken curve is result of no local dimming and the real line is the local dimming result. The numbers 1~6 of the x-axis in Figure 7 correspond to the six test patterns of Figure 6 in turn. Test results show that the contrast can be greatly improved by the proposed local dimming algorithm compared with unchangeable backlight. The contrast of figure 6(a) is even about 20000:1 because on the deep darkness in black region. We also tested many rigorous videos which have fast motion and violent spatial and temporal brightness change. No obvious visual artifacts were observed in the proposed system.

Conclusion

This paper discussed the backlight dimming technique on LCD-TV, analyzed the potential problems in local dimming system, and proposed a skillful local dimming algorithm which can achieve high static contrast more than 10000:1 and avoid annoying visual artifacts even when displaying rigorous video sequence. An additional effect of the local dimming system is the reduction of power consumption.

Local dimming method can also be implemented on CCFL backlight. But LED lights are much more powerful in local dimming system than traditional CCFL backlight, because the luminous intensity of LED can be changed in very short time and can be controlled linearly from full black to peak brightness by changing PWM period. Moreover, LED elements can be grouped into blocks very easily.

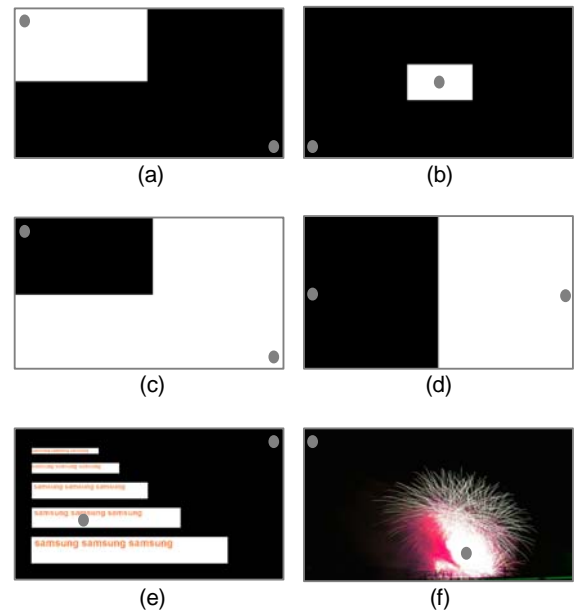## Acknowledgement

(a) (b) (c) (d) (e) (f)
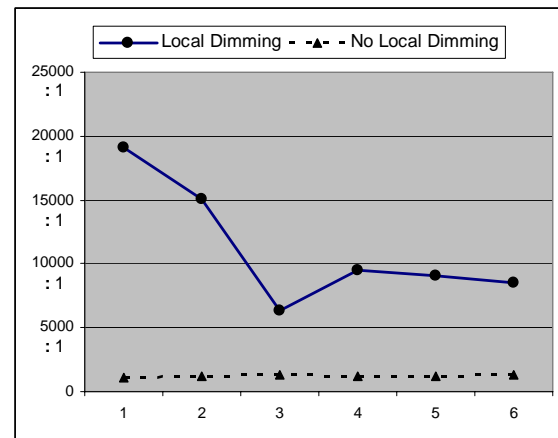
Figure 6. Test patterns

Figure 7. Contrasts of the test patterns in figure 6

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