Clipping Reduction Algorithm Using Backlight Luminance Compensation for Local Dimming in Liquid Crystal Displays

Jong-Ju Hong, Seong-Eun Kim, Student Member, IEEE, Woo-Jin Song, Member, IEEE
Dept. of Electronic and Electrical Engineering, Pohang University of Science and Technology, Pohang, Korea

Abstract—Local dimming techniques cause clipping artifacts in liquid crystal displays. To overcome the artifacts, backlight luminance should be compensated, which requires additional power consumption. In this work we propose a novel backlight luminance compensation algorithm to reduce clipping artifacts by minimizing increment of backlight luminance.

I. INTRODUCTION

Recently, local dimming techniques have been proposed to achieve high contrast ratio (CR) and low power consumption for liquid crystal displays (LCDs). In the local dimming system, the backlight is divided into several blocks and these are dimmed individually according to the image contents. In addition, the pixel values (gray levels) are compensated according to the reduced backlight in order to preserve the brightness [1]-[3]. However this approach causes clipping artifacts.

If a block is a dark region, backlight of the block is dimmed and pixel values are compensated. Among the compensated pixels, some high gray levels cannot be compensated sufficiently and clipped to the same gray level. The image with clipped pixels looks unnatural and sometimes reveals several contours [4]. The clipping can be reduced by increasing backlight luminance which results in additional power consumption and decreasing of CR. Therefore, we propose a novel backlight luminance compensation (BLC) algorithm to reduce clipping artifacts with optimum backlight dimming.

II. CLIPPING AND OPTIMUM BACKLIGHT LUMINANCE

LCDs are set to meet an ideal target luminance when backlight is fully turned on at each gray level illustrated as triangle dots in Fig. 1. However, since they have light leakage problem due to imperfectness of liquid crystals, real luminance curve is illustrated as dashed line in Fig. 1 [3]. The luminance curve is vertically shifted by the dimmed backlight. Assuming that backlight luminance of (i,j) block, B(i,j), is uniform, it is evaluated by dimming duties, d, of several surrounding blocks and their influences as follows [2]:

\[ B(i,j) = \sum_{m \in M} \sum_{r,s} c_{rs} \cdot d(i+r,j+s), \]  

where \( m = (M-1)/2 \), where \( M \) is a size of the block mask including neighboring blocks. \( c_{rs} \) is the backlight block spread function (BSF) coefficient which reflects the influence between \((i,j)\) block and each neighboring block. \( c_{rs} \) depends on the backlight structure and it is determined experimentally.

This work was supported by the Brain Korea (BK) 21 Program funded by the MEST, by LG-Display Co. and by the IT R&D program of MKE/MCST/IITA (2008-F-031-01, Korea.

Pixel values are compensated to achieve the target luminance curve \( f(g) \). However, maximum luminance is decreased from 1 to \( B \) on the normalized luminance curve due to dimmed backlight. Therefore, some high gray levels cannot achieve the target luminance and clipped. As shown in Fig. 1 (c), gray levels between \( g_r+1 \) and 255 are clipped. We reduce the clipped pixels by increasing the backlight luminance \( B \).

![Fig. 1 Normalized luminance of target luminance, backlight dimming, and pixel compensation](image)

\[ g_r(i,j) = f^{-1}(B(i,j)) = B(i,j)^{1/\gamma} \times 255. \]  

From (2), we can quantify clipping artifacts by defining clipping measure \( N \) as the number of clipped pixels as follows:

\[ N(i,j) = \sum_{g_r(i,j)=1}^{255} n(i,j,g), \]  

where \( n \) is the histogram of the given block image.

We can reduce clipping artifacts by restricting the clipping measure \( N \) to be less than a threshold (TH). To satisfy the restriction, \( g_r \) and corresponding \( B \) should be increased. However, the increment of backlight luminance is minimized to reduce additional power consumption. Therefore, \( g_r \) is increased until \( N \) is less than \( TH \). The optimum \( g_r \) is obtained by maximizing \( N \) subject to \( N \leq TH \) such as:

\[ g_r^{opt}(i,j) = \arg \max_{g_r(i,j) \in [1,255]} \sum_{n(i,j,g) \leq TH} n(i,j,g), \]  

The solution \( g_r^{opt} \) is iteratively obtained. The compatible matched backlight luminance \( B^{opt} \) corresponding to the \( g_r^{opt} \) can be obtained using (2). The final result \( B^{opt} \) is the optimum backlight luminance on the clipping constraint.
III. BACKLIGHT LUMINANCE COMPENSATION (BLC)

The final stage is to compensate the dimming duties to satisfy the optimum backlight luminance $B_{\text{opt}}$; this process is called backlight luminance compensation (BLC). To achieve $B_{\text{opt}}$, all dimming duties of $M \times M$ neighboring blocks surrounding $(i, j)$ should be compensated cooperatively because the backlight luminance is influenced by neighboring blocks at the same time [2]. Multiplying dimming duties by some scaling factors can increase the dimming duties:

$$d_{\text{opt}}(i + r, j + s) = \alpha_{s}(i, j) \cdot d(i + r, j + s),$$

where $\alpha$ ($\alpha \geq 1$) is a scaling factor that determines the ratio by which dimming duty is increased. Our objective is to find the scaling factors that minimize the increment of the dimming duties, $d_{\text{opt}} \cdot d$, satisfying the compensated backlight luminance to be larger than $B_{\text{opt}}$. BLC is to find the scaling factors as:

$$\{\alpha_{r,s}(i, j)\}_{r,s=[-m,m]} = \underset{\{\alpha_{r,s}(i, j)\}_{r,s=[-m,m]}}{\arg\min} \sum_{r=-m}^{m} \sum_{s=-m}^{m} d(i + r, j + s) \cdot \left(\alpha_{r,s}(i, j) - 1\right),$$

subject to

$$\sum_{r=-m}^{m} \sum_{s=-m}^{m} c_{r,s} \cdot \alpha_{r,s}(i, j) \cdot d(i + r, j + s) \geq B_{\text{opt}}(i, j).$$

To solve this constrained optimization problem, we use index rebuilding which is a different positional representation of the $M \times M$ blocks that surround $(i,j)$. Indices $r$ and $s$ are rebuilt to $k$ and $u$. First, blocks are sorted in decreasing order of the BSF among $M \times M$ blocks; $k$ is the block’s index in this list. $k$ is calculated on the assumption that $M = 3$ and $c_{r,s}$ has the same value when both $r$ and $s$ are not zero. Then for each BSF coefficient, blocks are sorted in decreasing order of dimming duty; $u$ is the block’s index in this list (Fig. 2).

This representation can be applied to the task of calculating the scaling factors. The scaling factor is calculated as:

Step 1: $a_{0,0}(i, j) = 1 + \left(B_{\text{opt}}(i, j) - B(i, j)\right)/\left[c_{0,0}(i, j)\right]$.  
Step 2: $a_{k,0}(i, j)$

$$= 1 + \left(c_{k-1,0} \cdot c_{k}\right) \cdot \left|a_{k-1,0}(i, j) \cdot d_{k-1,0}(i, j) - d_{\text{max}}\right|/\sum_{r=-m}^{m} d_{k,r}(i, j).$$

Step 3: $a_{k,u}(i, j)$

$$= a_{k,u-1}(i, j) + \left(c_{k,u-1}(i, j) \cdot d_{k,u-1}(i, j) - d_{\text{max}}\right) / \sum_{r=-m}^{m} d_{k,r}(i, j).$$

To satisfy (7), the best approach, minimizing increment of the dimming duties expressed as (6), is to increase only the dimming duty of the center block $d_{0,0}$ because $c_{0,0}$ is the largest among BSF coefficient (step 1), but this increased dimming duty, $a_{0,0}d_{0,0}$ might exceed the maximum value $d_{\text{max}}$. If this happens, it is fixed to the $d_{\text{max}}$ and the shortage, $a_{0,0}d_{0,0} - d_{\text{max}}$, is compensated for by adjusting the dimming duties of the next neighboring blocks (step 2). Here, the modified dimming duties can also exceed the $d_{\text{max}}$. Compared to step 2, the overflowed quantity is compensated for in the blocks having the same BSF coefficient because it is more effective than covering the shortage in the next neighboring blocks (step 3). The rest scaling factors are equal to the recent value.

IV. EXPERIMENTAL RESULTS

When clipping occurs in the image (APL [3]), the proposed algorithm remarkably enhances brightness and details (Fig. 3) and reduces clipping measure at suitable level (TABLE 1). In addition, the enhanced image shows good CR and the same quality as the original or “Max” algorithm [3]. The proposed algorithm increases backlight luminance because clipping artifacts are severely caused before applying the algorithm but it maintains the advantage of power consumption compared to “Max” algorithm enhancing backlight luminance excessively as shown in TABLE 1.

V. CONCLUSIONS

We have proposed a novel BLC algorithm which determines the optimal increment of backlight luminance by solving the proposed constraint minimization problem to reduce clipping artifacts. Experimental results show that the proposed algorithm reduces the clipping artifacts cost-effectively compared to “Max” algorithm.

REFERENCES


