An Adaptive Backlight Dimming with the Edge Enhancement Technique

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Abstract. Backlight dimming, which decreases the backlight luminance level and performs pixel compensation, is known as the most effective way to reduce the power consumption of portable electronic devices with LCD. In this paper, we propose an adaptive backlight dimming technique that preserves the quality of details in images even when the backlight luminance of LCD devices is greatly reduced. The proposed backlight dimming method consists of the following two steps: clipped point selection and image compensation. In the first step, to reduce power consumption, the proposed approach selects a suitable clipped point according to the chosen level for a given image based on the maximum and average value. In the second step, several parameters are adaptively chosen according to the characteristic of a given image. These parameters are then used to compensate pixels with an edge enhancement technique. The simulation results show that at the same clipping point the proposed method has higher detailed information than others.

1. Introduction
Liquid crystal displays (LCDs) are widely used in many kinds of portable electronic devices, such as wearable devices, smart phones, tablet personal computers, and laptop computers. With the increasing demand for portable handled devices, reducing their power consumption has become a very important issue. In terms of the overall system power consumption on those portable devices, LCD consumes 20%–45% of total system power due to different applications [1]. Furthermore, the backlight of an LCD accounts for the largest portion of the total power consumption. Hence, decreasing the backlight luminance level can significantly reduce the power consumption of LCD devices. However, this may cause significant changes in visual perception. To eliminate the visual changes, we can adjust the image brightness to the desired level by performing pixel compensation, which is a technique used for compensating gray levels of pixels to increase the transmittance level of liquid crystals (LCs). Backlight dimming, which decreases the backlight luminance level and performs pixel compensation, is known as the most effective way to reduce the power consumption of LCD devices.

![Figure 1 Overall block diagram of the global backlight dimming](image-url)
Generally, backlight dimming methods are divided into two kinds: global dimming algorithms [2]-[12] and local dimming algorithms [13]-[18]. Global dimming controls the backlight based on the luminance of entire image simultaneously, while local dimming splits the image area into several blocks and controls the brightness of each block separately. Local dimming has the advantage in regard to power management efficiency. However, the local dimming technique must be equipped with the appropriate LCD device which can adjust the backlight of each block individually, while the small size LCD usually does not contain this function. The local dimming algorithm also involves higher computational complexity. On the contrary, global dimming is more common for any kind of LCD than local dimming, and offers lower computational complexity.

In this paper, an adaptive backlight dimming method based on global dimming is presented. The rest of this paper is organized as below. In Section II, the related works are presented and the features of the proposed method is emphasized. In Section III, the proposed method is described in detail. In Section IV, the simulation results to evaluate image quality for the previous methods and the proposed method are presented. Finally, conclusions are given in Section V.

2. Related Works
Global dimming usually contains three procedures, as shown in Fig. 1. The main task of image analysis is to find a clipped point, which is the gray level of the reduced backlight luminance level, based on the characteristic of image. Then, the backlight luminance is modulated in the backlight modulation via the dimming rate which can be determined by the clipped point. The technique of the backlight modulation is pulse width modulation (PWM) in general. Finally, the luminance reduction resulting from backlight modulation is then compensated by image compensation. Therefore, the power consumption of the backlight can be saved while the brightness of image is still preserved in visual.

Although backlight dimming has been successfully applied, the backlight luminance level may be decreased below the maximum luminance level of a given image while the great reduction of power consumption is required. That means the gray levels above the clipped point cannot be restored. The distortion due to this problem is so called a clipping artifact. Clipping artifacts can degrade image quality severely. Hence, many researches focused on the two tasks, the optimal clipping point selection [6], [8]-[12] and pixel compensation [2]-[5], [7], [9], to obtain high image quality in visual. The optimal clipping point selection is an excellent idea to obtain high image quality according to the target peak signal-to-noise ratio (PSNR). However, the process of selection is an exhausted iteration with high computational complexity. The pixel compensation methods except [9] suffered from a problem that while in the low clipping point, the edge information of image is greatly reduced.

In this paper, avoiding high complexity for clipping point selection, a low complexity method, which selects the adaptive clipping point based on the maximum and average value of image, is presented. Then, the image is compensated by an edge enhancement method to preserve the detail information of image even in the low backlight luminance. The simulation results show that at the same clipping point the proposed methods has higher detailed information than others.

3. Proposed Method
The proposed backlight dimming method consists of the following two steps: clipped point selection and image compensation, which are illustrated in Fig. 2. In the first step, to reduce power consumption, the proposed approach selects a suitable clipped point according to the chosen level for a given image based on the maximum and average value. In the second step, several parameters are adaptively chosen according to the characteristic of a given image. These parameters are then used to compensate pixels with an edge enhancement technique. The operation of each step is described in detail as follows.
Find the maximum & minimum level

Divide the backlight into several levels

Select the clipped point based on level

FIEEMD

Extract the edge information

Calculate the parameters

Compensate the pixels

Figure 2 Flow diagram of the proposed algorithm.

3.1 Clipped Point Selection

Although the optimal clipping point selection is an excellent method to obtain high image quality according to the target peak signal-to-noise ratio (PSNR), the process of selection is an exhausted iteration with high computational complexity. The higher the computational complexity, the higher power consumption and longer processing time the algorithm requires during processing. It is always a tradeoff. In our method, avoiding high computational complexity, a low complexity clipping point selection is applied. First, the gray level data of input image are obtained from the value component $(V)$ of HSV domain (hue, saturation, and value), which are calculated as follows:

$$V(x, y) = \max(R(x, y), G(x, y), B(x, y)),$$

(1)

where $V(x, y)$ is the gray level of the pixel of input image located at the $(x, y)$ coordinate, $R(x, y)$, $G(x, y)$, and $B(x, y)$ are the three component of the RGB domain (red, green and blue) of input image, and max is the operation to find the maximum value among input elements.

Then, the maximum and average value of $V$ are calculated as below:

$$\text{Avg}_V = \frac{\sum_{i=0}^{H-1} \sum_{j=0}^{W-1} V(i, j)}{H \times W},$$

(2)

$$\text{Max}_V = \max_{V(i, j) \text{ for } i = 0, 1, \ldots, W - 1; j = 0, 1, \ldots, H - 1}.$$

(3)

where $W$ and $H$ are the width and height of the input image, respectively. While $\text{Max}_V$ is used as the clipping point, the compensated image yields almost no artifacts. While $\text{Avg}_V$ is applied as the clipping point, there may be about half the pixels suffering from distortion. Thus, $\text{Max}_V$ and $\text{Avg}_V$ are chosen as the maximum and minimum value of the clipping point respectively in our method. Besides, an adjustable level of output image quality is established for users that can reconstruct different image quality according to a given parameter $L_v$ [5], [7]. The mechanism of adjustment is show as follows:

$$\text{Diff} = \frac{(\text{Max}_V - \text{Avg}_V)}{8}.$$

(4)
where $BL$ is the clipping point according to different $Lv$. The greater the value of $Lv$, the higher the quality is, but the less reduction of power consumption the device can achieve.

### 3.2 Image compensation

Many pixel compensation methods suffered from a problem that while in the low clipping point, the edge information of image is greatly reduced. In our compensation method, the edge information is first extracted from the given image. After the pixels are compensated, the edge information is used to enhance the detail of image. The Retinex theory [19] is applied here to extract the edge information. The theory assumed that the intensity of visible light reaching a camera depends on the product of the illumination and the reflectance. Thus, an observed image can be expressed as below:

$$I(x, y) = L(x, y) \times D(x, y),$$

where $I(x, y)$ is the pixel of observed image located at $(x, y)$ coordinate, $L(x, y)$ is the illumination of the scene and $D(x, y)$ is the reflectance of the objects. In general, the illumination represents the ray of light source from the sun or sky, and the reflectance represents the detail information of the object surfaces.

To extract the reflectance $D$, the fast illumination estimation by using the concept of bi-dimensional empirical mode decomposition (FIEEMD) [20] is adopted here to estimate the illumination $L$. The estimation of $L$ is shown as follows:

$$E'_V(x, y) = local_{\max}_{(i,j)\in \Omega(x,y)} (V(i, j)),$$

$$E'_I(x, y) = local_{\min}_{(i,j)\in \Omega(x,y)} (V(i, j)),$$

$$L(x, y) = \frac{E'_V(x, y) + E'_I(x, y)}{2}$$

where $\Omega(x, y)$ is a square region of size $3 \times 3$ centered at the $(x, y)$ coordinate, $local_{\max}$ and $local_{\min}$ are operations to find the local maximum and minimum value among the square region $\Omega(x, y)$, respectively. Once the illumination $L$ is obtained, the reflectance $D$ can be extracted as below:

$$D(x, y) = \frac{I(x, y)}{L(x, y)},$$

The reflectance $D$ is then saved as the edge information of input image.

The second step of image compensation is to prepare the parameters for the pixel compensation. Figure 3 shows the common id of the pixel compensation. The black line shows the original pixels without backlight dimming. The dot line represents the pixels after backlight dimming without pixel compensation. After pixel compensation, the red line shows the pixels with clipping artifacts where the pixels whose gray levels beyond the clipped point are saturated at the clipped point. To smooth clipping artifacts, a method with two points is adopted in our method as show in Fig. 4. The advantage of two-point method is that the gradient among pixels whose original gray levels are around the clipped point can be reduced. The values of $A$ and $B$ are determined as follows:

$$A_1 = BL \times 0.5,$$

$$A_2 = BL + (255 - BL) \times 0.25,$$

In the pixel compensation step, a gamma correction is adopted in our method which is combined with gamma correction method described above. Figure 5 presents the transformation curve of two-point method with gamma correction. If $V(x,y) \leq A_1$, the parameter $\gamma_1$ is chosen. If $A_1 < V(x,y) \leq A_2$, the
parameter $\gamma_2$ is chosen. If $A_1 < V(x,y) \leq 255$, the parameter $\gamma_3$ is chosen. In this paper, $\gamma_1$, $\gamma_2$, and $\gamma_3$, are selected as 0.9, 0.3, and 1, respectively. After the compensated image $V'$ is obtained, the reflectance $D$ is then combined with the compensated image $V'$ to produce edge enhancement image $V''$ by using the formula as below:

$$V'(x,y) = V'(x,y) \times D(x,y).$$

(13)

According to [7], the reconstruction of the output image with RGB domain can be derived by using $V''$ as the following equations.

$$
\begin{bmatrix}
R'(x,y) \\
G'(x,y) \\
B'(x,y)
\end{bmatrix} = k \begin{bmatrix}
R(x,y) \\
G(x,y) \\
B(x,y)
\end{bmatrix},
$$

(14)

where

$$k = \frac{V'(x,y)}{V(x,y)}. $$

(15)

**Figure 3** Common idea of pixel compensation

**Figure 4** Two-point method of pixel compensation.

**Figure 5** Two-point method with gamma correction.

4. Simulation Results

Several experiments were performed to evaluate the objective and subjective performance of the proposed method. For objective assessment, the PSNR, discrete entropy (DE) [21], and edge-based contrast measure (EBCM) [22] are applied as quantitative measures. The PSNR can show the distortion between the original image and the compensated image. The higher PSNR means the less distortion. The DE of image $I$ measures the content of image, in which a higher value indicates that an image has more detail information. The EBCM is based on the observation that human perception mechanisms are very sensitive to edges. Thus, it is suitable for evaluating the contrast of images. The gray level corresponding to object contours is obtained by computing the average value of the pixel gray levels weighted by their edge values.
We use eight testing images to explore the performance of objective testing for the five image compensation methods. The compared results of PSNR, DE, and EBCM for the five methods are shown in Table I, Table II, and Table III, respectively. Note that the clipped points (BL) of all five methods are the same. It can be seen that the proposed methods obtains the comparable image quality as compared with other methods in PSNR. In DE and EBCM, our method is the best one among these five methods. That means our method can really enhance the edge information. Figure 6-7 show the close-up views of image results under the lower clipped point to illustrate the performance of visual quality with the five methods. It can be seen that our method can efficiently enhance the details of the image to obtain the better results as compared with other methods.

![Figure 6](image_url)

**Figure 6** The close-up view of hair with five methods. (a) the original image, (b) the proposed method, (c) [4], (d) [5], (e) [6], (f) [9].

**Table 1** Comparison of psnr for image compensation with five methods.

| Image    | BL | [4]   | [5]   | [6]   | [9]   | Proposed |
|----------|-----|-------|-------|-------|-------|----------|
| House    | 178 | 15.282| 19.636| 18.223| 17.069| 18.5799  |
| Motor    | 156 | 16.269| 23.196| 20.343| 19.504| 22.1741  |
| Girl     | 179 | 16.010| 17.839| 17.398| 16.571| 17.1146  |
| Bird     | 178 | 16.127| 22.798| 20.374| 19.676| 21.9667  |
| Hat      | 169 | 15.782| 26.771| 20.939| 20.913| 24.6183  |
| Barn     | 174 | 15.318| 25.178| 20.360| 19.615| 23.1582  |
| Lighthouse | 178 | 15.184| 26.708| 20.672| 20.509| 23.2433  |
| Mountain | 168 | 15.554| 21.716| 19.194| 17.782| 19.9809  |
Figure 7: The close-up view of house with five methods. (a) the original image, (b) the proposed method, (c) [4], (d) [5], (e) [6], (f) [9].

Table 2: Comparison of DE for image compensation with five methods.

| Image     | BL  | [4]   | [5]   | [6]   | [9]   | Proposed |
|-----------|-----|-------|-------|-------|-------|----------|
| House     | 178 | 4.4834| 4.2645| 4.5106| 4.6698| 4.6322   |
| Motor     | 156 | 4.5814| 4.5646| 4.7229| 4.7156| 4.8341   |
| Girl      | 179 | 4.2887| 4.0131| 4.2754| 4.4984| 4.5179   |
| Bird      | 178 | 4.7032| 4.2674| 4.5761| 4.6406| 4.7099   |
| Hat       | 169 | 4.5177| 4.4740| 4.6347| 4.6361| 4.7228   |
| Barn      | 174 | 4.4747| 4.5168| 4.6266| 4.6072| 4.6903   |
| Lighthouse| 178 | 4.2264| 4.4516| 4.4229| 4.4185| 4.5189   |
| Mountain  | 168 | 4.5612| 4.4430| 4.6526| 4.6878| 4.7185   |

Table 3: Comparison of EBCM for image compensation with five methods.

| Image     | BL  | [4]   | [5]   | [6]   | [9]   | Proposed |
|-----------|-----|-------|-------|-------|-------|----------|
| House     | 178 | 0.0846| 0.0674| 0.0709| 0.0795| 0.1157   |
| Motor     | 156 | 0.0852| 0.0771| 0.0819| 0.0822| 0.1237   |
| Girl      | 179 | 0.0454| 0.0402| 0.0440| 0.0445| 0.0624   |
| Bird      | 178 | 0.0325| 0.0285| 0.0306| 0.0308| 0.0383   |
| Hat       | 169 | 0.0345| 0.0316| 0.0335| 0.0355| 0.0436   |
| Barn      | 174 | 0.0441| 0.0399| 0.0428| 0.0429| 0.0588   |
| Lighthouse| 178 | 0.0531| 0.0473| 0.0521| 0.0521| 0.0755   |
| Mountain  | 168 | 0.0843| 0.0700| 0.0782| 0.0792| 0.1183   |
5. Conclusion
In this paper, an adaptive backlight dimming technique is proposed. This technique preserves the quality of details in images even when the backlight luminance of LCD devices is greatly reduced. The proposed backlight dimming method consists of the following two steps: clipped point selection and image compensation. In the first step, to reduce power consumption, the proposed approach selects a suitable clipped point according to the chosen level for a given image based on the maximum and average value. In the second step, several parameters are adaptively chosen according to the characteristic of a given image. These parameters are then used to compensate pixels with an edge enhancement technique. The simulation results show that at the same clipping point the proposed method can efficiently enhance the details of the image to obtain the better results as compared with other methods.

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7. References
[1] I. Choi, H. Shim, and N. Chang, “Low-power color TFT LCD display for handheld embedded systems,” in Proc. Int. Symp. Low-Power Electron. Des., Aug. 2002, pp. 112–117.
[2] P. Tsai, C. Liang, T. Huang, and H. H. Chen, “Image enhancement for backlight-scaled TFT-LCD displays,” IEEE Trans. Circuits Syst. Video Technol., vol. 19, no. 4, pp. 574–583, Apr. 2009.
[3] N. Chang, I. Choi, and H. Shim, “DLS: Dynamic backlight luminance scaling of liquid crystal display,” IEEE Trans. Very Large Scale Integr. Syst., vol. 12, no. 8, pp. 837–846, Aug. 2004.
[4] C. Lai and C. Tsai, “Backlight Power Reduction and Image Contrast Enhancement Using Adaptive Dimming for Global Backlight Applications,” IEEE Trans. Consumer Electron., vol. 54, no. 2, pp. 669-674, May 2008.
[5] H. Cho and O. Kwon, “A backlight dimming algorithm for low power and high image quality LCD applications,” IEEE Trans. Consumer Electron., vol. 55, no. 2, pp. 839–844, May 2009.
[6] S. Kang and Y. Kim, “Image integrity-based gray-level error control for low power liquid crystal displays,” IEEE Trans. Consumer Electron., vol. 55, no. 4, pp. 2401–2406, Nov. 2009.
[7] Y. Lai, Y. Lai, and P. Chen, “Content-based LCD backlight power reduction with image contrast enhancement using histogram analysis,” J. Display Technol., vol. 7, no. 10, pp. 550–555, Oct. 2011.
[8] S.-J. Kang and Y. H. Kim, “Multi-histogram-based backlight dimming for low power liquid crystal displays,” J. Display Technol., vol. 7, no. 10, pp. 544–549, Oct. 2011.
[9] S. I. Cho, S.-J. Kang, and Y. H. Kim, “Image quality-aware backlight dimming with color and detail enhancement techniques,” J. Display Technol., vol. 9, no. 2, pp. 112–121, Feb. 2013.
[10] S.-J. Kang and Y. H. Kim, “Segmentation-based clipped error control algorithm for global backlight dimming,” J. Display Technol., vol. 10, no. 7, pp. 568–573, Jul. 2014.
[11] S.-J. Kang, S. Bae, J.-J. Yun, and M.-Y. Lee, “Color Distortion-Aware Error Control for Backlight Dimming,” J. Display Technol., vol. 11, no. 1, pp. 79–85, Jun. 2015.
[12] S.-J. Kang and S. Bae, “Fast Segmentation-Based Backlight Dimming,” J. Display Technol., vol. 11, no. 5, pp. 399–402, May. 2015.
[13] H. Chen, J. Sung, T. Ha, Y. Park, and C. Hong, “Backlight local dimming algorithm for high contrast LCD-TV,” in Proc. ASID, Oct. 2006, pp. 168–171.
[14] H. Chen, J. Sung, T. Ha, and Y. Park, “Locally pixel-compensated backlight dimming for improving static contrast on LED backlight LCDs,” in SID 07 Dig., May 2007, pp. 1339–1342.
[15] J. Hong, S. Kim, and W. Song, “A clipping reduction algorithm using backlight luminance compensation for local dimming liquid crystal displays,” IEEE Trans. Consumer Electron., vol. 56, no. 1, pp. 240–246, Feb. 2010.
[16] X. Zhang, R. Wang, D. Dong, J. Han, and H. Wu, “Dynamic backlight adaptation based on the details of image for liquid crystal displays,” J. Display Technol., vol. 8, no. 2, pp. 108–111, Feb. 2012.
[17] H. Cho, B. Cho, H. Hong, E. Oh, and O. Kwon, “A color local dimming algorithm for liquid crystals displays using color light emitting diode backlight systems,” Opt. Laser Technol., vol. 47, pp. 80–87, Apr. 2013.

[18] S.-C. Hsiai, M.-H. Sheu, J.-R. Chang Chien, and S.-K. Wang, “High-Performance Local Dimming Algorithm and Its Hardware Implementation for LCD Backlight,” J. Display Technol., vol. 9, no. 7, pp. 527–535, July 2013.

[19] E. H. Land and J. J. Mccann, “Lightness and retinex theory,” J. Opt. Soc. Am., vol. 61, no. 1, pp. 1–11, Jan. 1971.

[20] Y.-H. Shiau, P.-Y. Chen, H.-Y. Yang and S.-Y. Li, “A Low-Cost Hardware Architecture for Illumination Adjustment in Real-Time Applications,” IEEE Trans. on Intelligent Transportation Systems, vol. 16, pp. 934–946, April 2015.

[21] C. E. Shannon, “A mathematical theory of communication,” Bell Syst. Tech. J., vol. 27, pp. 379–423, Jul. Oct., 1948.

[22] A. Beghdadi and A. L. Negrate, “Contrast enhancement technique based on local detection of edges,” Comput. Vis. Graph. Image Process., vol. 46, no. 2, pp. 162–174, May 1989.