IMAGE QUALITY ENHANCEMENT FOR LOW BACKLIGHT TFT–LCD DISPLAYS

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ABSTRACT

Reducing LCD backlight saves power consumption of a portable device, but it also decreases the contrast and brightness of the displayed image. Previous approaches adjust the backlight level frame by frame to reach a specified image quality level without optimizing the image quality. In contrast, the proposed method adjusts the backlight to meet the target power level while maintaining the image quality. This is achieved by performing brightness compensation and local contrast enhancement in accordance with the given backlight level. Experimental results show that the proposed algorithm outperforms previous methods.

***Index Terms*—**Power management, backlight, image enhancement, contrast.

1. INTRODUCTION

Thin-film transistor (TFT) liquid crystal display (LCD) is a basic component for most hand-held devices. However, cold cathode fluorescent lamp (CCFL)—the main light source of TFT-LCD—consumes considerable power. In practice, most portable devices extend the battery life by reducing the LCD backlight.

As the backlight decreases, both brightness and contrast (and hence the fidelity) of the image drop, as shown in Fig. 1. Here the image fidelity is defined as the resemblance of the backlight-scaled image to the original image. There is no fidelity loss if the backlight-scaled image is identical to the original image.

Most previous work determines the backlight level by dynamically switching the backlight and applying various luminance compensations to the image until it reaches a pre-specified fidelity level. The brightness is equal to the product of the backlight and the transmittance of the LCD. The techniques proposed in [3], [4] boost the pixel value to maintain the image brightness based on the property that the LCD transmittance monotonically increases with pixel value [6]. However, pixels with high intensity are clipped after boosting, resulting in a loss of image details and quality.


(a)

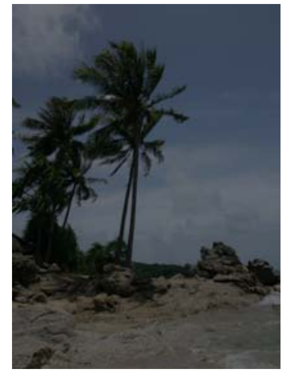
(b)

Fig. 1 (a) Original image, (b) image under dim backlight.

The concurrent brightness and contrast scaling (CBCS) method [5] adjusts the backlight level and compensation coefficients to maintain the global contrast fidelity. It is based on the assumption that pixel intensity is distributed in a small range; therefore, this method is not suitable for general images. Liang et al. [6] incorporate an objective quality distortion function (mean square error) into the backlight switching strategy and propose a quality-adaptive backlight scaling (QABS) scheme. But the objective quality metric does not correlate well with the subjective quality judged by the human visual system (HVS) [1], [2].

Unlike previous approaches, the algorithm proposed in this paper preserves contrast (rather than brightness) according to the characteristics of HVS, and it works without frequently switching the backlight. The local contrast characteristics of HVS are also taken into consideration in the design of the algorithm which preserves most details in both bright and dark regions.

The paper is organized as follows. In Section 2, we introduce the principle of the LCD display. The details of the proposed method are described in Section 3. In Section 4 the experimental results and performance evaluations are presented. Finally, the summary is given in Section 5.

2. BACKGROUND

2.1. Characteristics of human visual system

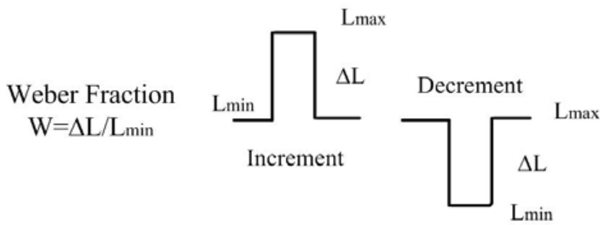

Fig. 2 Definition of contrast and its illustration [8].

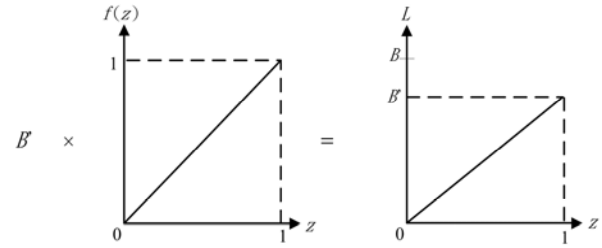

Fig. 3 The luminance function is the product of the backlight B' and the transmittance function $f(z)$.

Fig. 4 Clipped image of Fig. 1 (b=0.5).

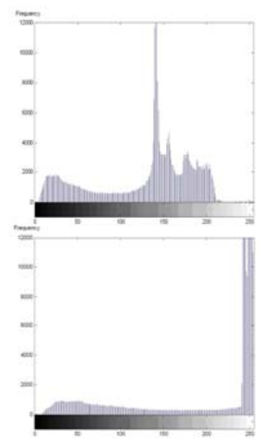

Fig. 5 Image histogram before (top) and after (bottom) boosting and clipping.

Contrast is the visual difference that makes an object distinguishable from other objects and the background. Human eyes are more sensitive to contrast than absolute luminance. Therefore, the relation of intensity between neighboring pixels is far more important than the absolute brightness [7].

There are several definitions of contrast. In this paper we adopt Weber's Law [8], which defines as the ratio of step increment or decrement to the background luminance. This is illustrated in Fig. 2, where ΔL is the illumination increment or decrement, and L is background illumination.

2.2. Characteristics of LCD

TFT-LCD is the most popular flat-panel display in consumer electronics. Since an LCD panel does not illuminate itself, it requires a light source. Most displays take CCFL as backlight, which normally consumes a significant portion (20–40%) of the total system power. Depending on the type of light source, there are three kinds of LCD displays. One is reflective LCD. It uses ambient light and reflector instead of the backlight, but it is not suitable for quality display. Another is transflective LCD. It is the one with complementary use of the backlight and the ambient light. It is usually used for small portable devices. The other is transmissive LCD. For this kind of display, all pixels are illuminated by the backlight from behind. Unlike the other components in portable devices, the light source of the display can not be shut down to prolong battery life because a transmissive LCD displays nothing when the backlight is turned off. Even transflective screens with two light sources perform poorly without backlight.

The perceived brightness L of a pixel displayed by the transmissive LCD is directly proportional to the product of its transmittance $f(z)$ and backlight illumination B. The transmittance of a pixel is a function of pixel value z. This represents that a pixel with value zero has no transmittance, so one can consider that no light is emitted from the backlight for that pixel. On the other hand, if the pixel value represented by an 8-bit integer is 255, the transmittance is one, and the perceived light is white. The relationship discussed above can be represented by:

$$L = B \times b \times f(z), \tag{1}$$

where we consider that the ambient light, if present, does not affect the image quality, $f(z)$ is the transmittance function, and b is the backlight factor that determines the quantity of backlight($0 \le b \le 1$), b=1 for full backlight, and b=0 for no backlight. Fig. 3 shows a graphical illustration of (1) and assumes that the transmittance is a linear function of the pixel value that is normalized to [0, 1]. Note that $B' = B \times b$.

When $b < 1$, backlight reduces so the pixel value z should be boosted [6] to maintain the display luminance L invariable to keep the image quality. Note that the transmittance is a linear mapping from pixel value ([0, 255]) to [0, 1]. Due to the finite bit length, z' must be clipped if z is too high or if the backlight factor b is too low. The compensation function is described by:

$$z' = z / b,$$
$$z' = \begin{cases} z', & \text{if } z' \le 255 \\ 255, & \text{if } z' > 255 \end{cases}. \tag{2}$$

Fig. 4 shows the image after applying (2), and Fig. 5 is the intensity histogram of the image before and after boosting and clipping. We can see that the details of the sky and the ground are lost after clipping.

3. ALGORITHM

As mentioned earlier, reducing backlight lowers image contrast and brightness. In order to compensate these, the proposed algorithm consists of two main steps: content-dependent brightness compensation and local contrast boost. The flow chart of the algorithm is shown in Fig. 6.

3.1. Brightness compensation

Pure brightness compensation without considering image characteristics causes the image quality degradation easily when overall average intensity is high. An adaptive compensation threshold θ depending on global intensity average is considered in the first step of our algorithm to prevent pixels from oversaturation when the original image is bright.

The details of the brightness compensation step are described as follows. First, determine θ according to the backlight factor b and the global intensity average μ_z:

$$\theta = \begin{cases} \theta_{\min}, & \text{if } \mu_z < 64 \\ (\mu_z - 64)\dfrac{(\theta_{\max} - \theta_{\min})}{128 - 64} + \theta_{\min}, & \text{if } 64 \le \mu_z < 128 \\ \theta_{\max}, & \text{otherwise} \end{cases} \quad (3)$$

where $\theta_{\min} = 255 \times b$ and $\theta_{\max} = 255$. The above formula is based on the observation that the global average of most images ranges between 64 and 128. When the global average of an image is higher than 128, an excessively low θ may cause over-saturation, so θ should set high. On the other hand, when the global average is low, θ is set low so that we can obtain more brightness compensation. When $64 \le \mu_z < 128$, θ is a linear function of the global average.

Depending on θ , we build up a brightness compensation function. The bench mark average μ_{bench} is computed by:

$$\mu_{bench} = \begin{cases} \dfrac{2}{3} \times \left\{ m \times (\mu_{local} - \theta_{\min})^2 + n \right\} + \dfrac{1}{3} \times \left(255 \times \dfrac{\mu_{local}}{\theta} \right), & \text{if } \mu_{local} \le \theta_{\min} \\ \dfrac{255 - n}{\theta - \theta_{\min}} \times (\mu_{local} - \theta_{\min}) + n, & \text{if } \theta_{\min} < \mu_{local} \le \theta \\ 255, & \text{otherwise.} \end{cases} \quad (4)$$

where, $n = 255 \times \theta_{\min} / \theta$, $m = -n / \theta_{\min}^2$, and μ_{local} is the local average, and it is the weighting average in a 3-by-3 window:

$$\mu_{local} = \frac{1}{M} \sum_{i=0}^{8} w_i z_i , \quad (5)$$

where w_i denotes the weight, and M is the sum of the weights. We use this equation to obtain μ_{local} of each pixel and increase it to μ_{bench} in equation (4) for brightness compensation. Note that we apply a linear and quadratic equation alternatively according to the local average.

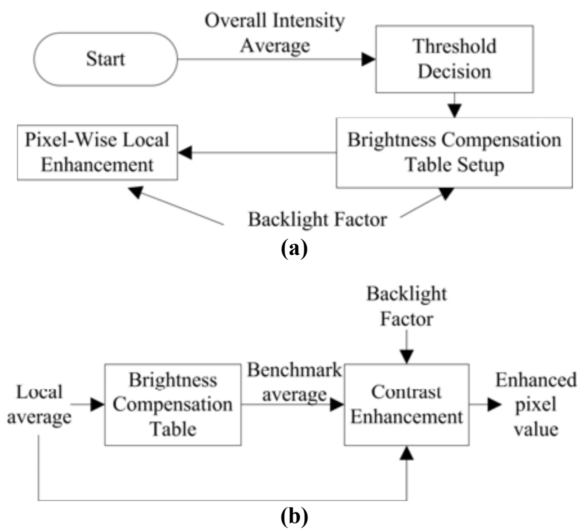

Fig. 6(a) Flow chart of the proposed system, (b) flow chart of local contrast enhancement per pixel.

3.2. Contrast boost

After μ_{bench} and μ_{local} are obtained, the enhanced pixel value z' is obtained by

$$z' = (1/b) \times (\mu_{bench} / \mu_{local}) \times (z - \mu_{local}) + \mu_{bench}. \quad (6)$$

where z is the original pixel value.

Human vision is sensitive to local contrast so we apply Weber's law [8] to enhance the contrast. In our algorithm, μ_{local} is considered as L and (z - μ_{local}) as ΔL in Fig. (2). In order to maintain the contrast, ΔL should be increased when L becomes larger. Note that *1/b* is simply a factor used to compensate the loss of contrast due to the scale-down of the backlight.

4. EXPERIMENTAL RESULT

A set of images taken by the authors are tested to compare our algorithm against QABS. In the performance comparison, in order to prevent color transformation from affecting the comparison, we apply the same transform function to both algorithms. The experimental results of the two algorithms on three images are shown in Figs. 7–9. At a high backlight level (Fig. 7 (b)), QABS can retain most edges. However, at low backlight, the image distortion caused by clipping appears, as we can see in Fig. 7 (a) where the edges of the windows (especially the windows at the center of the picture) are lost and the white lines of the building also vanish. On the contrary, the proposed method preserves most edges at various backlight levels, see Figs. 7 (c)–(d). The other results of our algorithm are also shown on in Figs. 8–9. In Fig. 9(a), it is also obvious that buildings

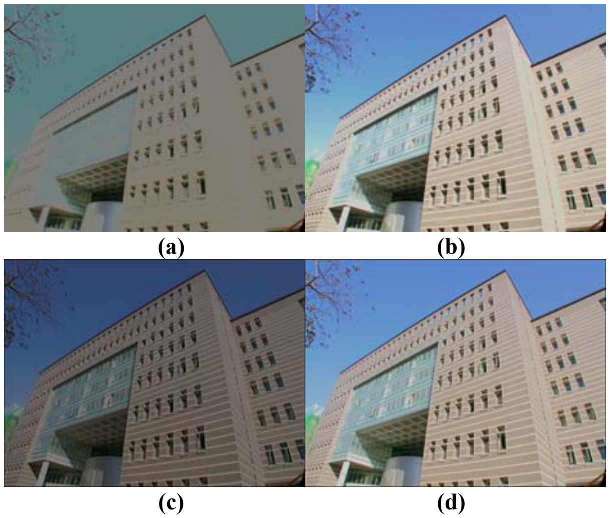

Fig. 7 Results of (a) QABS (b = 0.5), (b) QABS (b = 0.8), (c) the proposed method (b = 0.5), and (d) the proposed method (b = 0.8).

Fig. 9 Results of (a) QABS (b = 0.5, top), (b) the proposed method (b = 0.5, bottom).

circled by white line are over-saturation because of boosting and clipping. Fig. 9 (b) shows that our algorithm can preserve most details in both bright and dark regions.

In this algorithm, the weighting parameters and their sum used in computing the local average are all exponentials of 2. Incorporating this with arithmetic shift, computational complexity can be reduced.

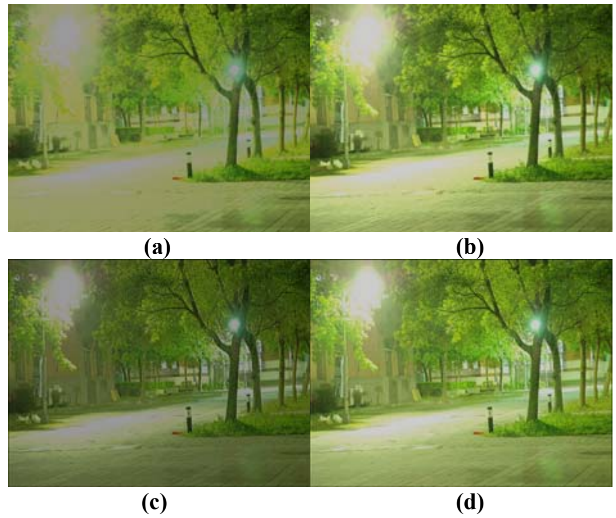

Fig. 8 Results of (a) QABS (b = 0.6), (b) QABS (b = 0.8), (c) the proposed method (b = 0.6), and (d) the proposed method (b = 0.8).

5. CONCLUTIONS

In this paper, an image quality enhancement algorithm based on local enhancement for low backlight TFT-LCD displays has been presented. This technique aims at maintaining the image perceptual quality through appropriate contrast preserving according to the image statistics and backlight level. Experimental results show that the proposed algorithm performs well at various backlight levels.

6. REFERENCES

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