HISTOGRAM SHRINKING FOR POWER-SAVING CONTRAST ENHANCEMENT

Yan-Tsung Peng, Fan-Chieh Cheng, Li-Ming Jan, and Shanq-Jang Ruan

Department of Electronic and Computer Engineering,
National Taiwan University of Science and Technology,
Taipei 10607, Taiwan.
E-mail: sjruan@mail.ntust.edu.tw

ABSTRACT

In this paper, a power-saving method for emissive display by shrinking histogram is proposed. Based on a modern pixel-level power model of an OLED module, the power consumption factor can be employed in the objective function. Nevertheless, contrast enhancement intrinsically contradicts saving power. In order to solve this problem, we formulate a new objective function which is subject to the constant entropy. By minimizing the distance between two near non-empty bins of image histogram, the power reduction and entropy preservation are simultaneously achieved. To further enhance the perceptional quality, the proposed method is also integrated with other related algorithms. Experimental results show that the proposed method is capable of reducing display power, while the performance of contrast enhancement is also improved.

***Index Terms*—** Contrast enhancement, histogram equalization, power saving.

1. INTRODUCTION

Display devices that play colorful photographs have been produced by the advanced imaging technology nowadays. However, the image quality is usually degraded because of low luminance in the poor lighting environment. Therefore, digital images are often post-processed to bring out several features, such as edge, saturation, chroma, contrast, and brightness. For achieving better human experience, contrast is the most significant factor that affects the visual perception. Hence, image enhancement algorithms which focus on improving contrast are widely developed. For example, the histogram equalization (HE) method is frequently adopted to enhance contrast [1–3].

In recent years, smart phones and other multimedia devices are dramatically produced. For better human visual experience, the resolution of display panels is getting bigger and bigger, which makes the power consumption of display panel more important and essential. Moreover, the limitation of the battery life is also a critical issue on hand-held devices. As the quality of images is improved, the energy limitation of display devices must be featured. In other words, the balance between contrast enhancement and power-saving is a significant problem in modern display devices. Therefore, image processing (IP) algorithm is expected to enhance contrast as well as to reduce power in display panels.

Generally speaking, a specific IP algorithm is directly created by analysing image data using mathematical process. However, power-constrained IP design must consider the property of display panels. Based on the characteristics of light source, display panels can be categorized into non-emissive and emissive types. Thin-film transistor liquid crystal display (TFT-LCD) is one of non-emissive display panels [4]. Since LCD is non-emissive, the intensity of pixels is controlled by the backlight. Nevertheless, TFT-LCD still has the highest market share as the backlight module is simple to be manufactured. Plasma display panels (PDPs), organic lightemitting diode (OLED), field emissive displays (FED) are three well-known emissive panels. Compared to the traditional TFT-LCD, emissive techniques directly produce image without external backlight module. That is, the light of each pixel can be individually turned to enhance the contrast ratio. Furthermore, the power consumption of a pixel is directly proportioned to its intensity, which provides convenience to design the advanced IP algorithm. Hence, the development of emissive technique is being active for next-generation of display panels.

There are several IP algorithms that balance contrast enhancement and power consumption in display panels. With the decreased backlight factor in the display module, contrast enhancement using image decomposition is employed to preserve the perceived quality [4]. To prevent high gray-level errors in pixels from happening, PSNR is maximized among multiple histograms to select the clipped rate of backlight [5]. For hardware implementation, the absolute difference between median and mean values is computed to evaluate backlight factor, while the straightforward piecewise-linear function is used to transform pixel value [6]. Unfortunately, backlight dimming algorithms are devised to adjust LCD module,

This work was supports by National Science Council under the Grant NSC 101-2221-E-011-164-MY3.

which does not exist in emissive display panels.

Based on HE method and logarithm function, Lee *et al.* made an attempt on the OLED display [2]. Compared to the traditional optimization method [1], the power-constrained contrast enhancement (PCCE) algorithm [2] added a power term to the objective function. Although the PCCE algorithm successfully enhances the contrast of image, the power ratio still depends on the power-control parameter. If the PCCE algorithm is applied to OLED panel, such a parameter must be regulated for different kinds of images. Moreover, the term of power reduction based on PCCE results in the degradation of image contrast.

In this paper, a histogram shrinking (HS) algorithm is proposed to automatically reduce power of the modern panel. For real-time applications, it only involves a subtraction operator to efficiently improve contrast enhancement algorithms. It is also developed with entropy preservation that is appropriate for high perceptual quality.

The rest of this paper is organized as follows: Section 2 develops the entropy preservation model to power consumption and proposes the HS algorithm. Section 3 presents experimental results. Finally, Section 4 concludes this paper.

2. PROPOSED METHOD

Based on the emissive property of pixels, a pixel-level power model of an OLED module had been presented in [7]. Let ω_s be static power, the presented power model of a single-color pixel is formulated by

$$P = \omega_s + \sum_{e \in \{R,G,B\}} \omega_e (l_e)^\gamma, \tag{1}$$

where γ is the parameter of gamma correction, l_e is the value of each color channel, and ω_e is the weighting coefficient. After ignoring ω_s and ω_e, the total dissipated power (TDP) for a grayscale image is modeled as

$$\text{TDP} = \sum_{n=0}^{N-1} (Y_n)^\gamma, \tag{2}$$

where Y_n represents each pixel value and N is the total number of pixels. The PCCE algorithm [2] minimized TDP to achieve low power design, but it also degraded image quality as the optimization function has contradictory terms.

In order to solve this problem, we model a new objective function with entropy preservation, i.e.,

$$\text{minimize TDP subject to } \Delta E \equiv 0, \tag{3}$$

where ΔE is the entropy distortion of the image after power reduction. For a grayscale image, the entropy function can be easily expressed as

$$E = -\sum_{l=0}^{255} pdf(l) \log(pdf(l)), \tag{4}$$

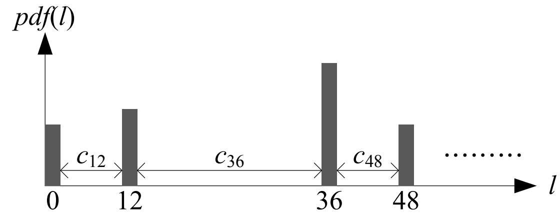

Fig. 1. The consecutive empty bins of the histogram.

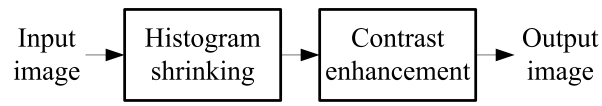

Fig. 2. The flowchart of the proposed HS method for contrast enhancement.

where l represents each gray-level and $pdf(l)$ is the probability normalized from the image histogram. Note that the summation is subject to $pdf(l) > 0$ because of the definition of logarithm function. According to the characteristic of entropy, a higher E indicates the richer details of an image.

To make it convenient to observe, eq. (2) is also written with *pdf* as follows:

$$\text{TDP} = N \sum_{l=0}^{255} pdf(l) l^\gamma. \tag{5}$$

To lower TDP, a straightforward method can be designed. Let d_l be the power-saving parameter corresponding to gray-level l. The output value can be calculated as

$$T(l) = l - d_l. \tag{6}$$

We notice that eq. (6) must achieve the constancy of entropy. Hence, the output $T(l)$ is subject to $pdf(T(l)) \equiv 0$. That is, the combination of any two non-empty bins that exists in the input image histogram is not permitted. After applying the subtraction operator to all pixels, the power-saving value can be denoted as

$$\Delta P = \sum_{l=0}^{255} d_l. \tag{7}$$

Inspired by the cumulative distribution function (*cdf*) of HE method, we further evaluate the cumulative power-saving value. Let c_i be the length between two non-empty bins. The power-saving value can be expressed as

$$d_l = \sum_{i=0}^{l} c_i. \tag{8}$$

Fig. 1 shows the length of the consecutive empty bins. For two near non-empty bins, the maximum value of shrinking distance just equals the account of empty bins between them. The pseudo-code of the proposed HS method is then described below:

```
Input: Image I of size w × h
Output: Low-power image I' of size w × h
Compute the normalized histogram denoted as pdf
Initialize d to be empty vector of size 1 × 256
Initialize counter c as 0
for l ← 0 to 255 do
    if pdf(l) ≡ 0 then
        c = c + 1
    else
        d_l = c
    end if
end for
for y ← 1 to h do
    for x ← 1 to w do
        I'(x, y) = I(x, y) − d_{I(x,y)}
    end for
end for
```

Based on the HS algorithm, Fig. 2 shows the proposed flow diagram for improving contrast enhancement.

3. EXPERIMENTAL RESULTS

We simulate the power reduction produced by the proposed HS method. Besides, the improvement of contrast enhancement using the HS method is also discussed. To test the performance of our flow diagram, we apply two methods named Contextual Variation Contrast (CVC) method [1], and Adaptive Gamma Correction with Weighting Distribution (AGCWD) method [3]. For the objective evaluation, the traditional measure of enhancement (EME) [8] is utilized in our experiments. Let the input image be divided into $k_1 \times k_2$ non-overlapping sub-blocks I_{ij}, the EME is computed as

$$\mathrm{EME}(I) = \sum_{i=1}^{k_1} \sum_{j=1}^{k_2} 20 \ln \frac{\max(I_{ij})}{\min(I_{ij})}. \tag{9}$$

Note that the minimum denominator must be 1.

Fig. 3 shows the output image by each method. For objective assessment, the corresponding EME and average TDP values are listed in Table 1 and Table 2. Notice that average TDP is computed by TDP/N. For power reduction, the HS method computes d_l to decrease the pixel value directly. After shrinking the histogram, the non-empty bins become continuous. Therefore, the HS method can also improve the HE-based methods using cdf. As a result, we can easily observe that the HS method is very effective to improve contrast ratio and to reduce power.

For each pixel, time complexity of the HS method belongs to $O(1)$. Specifically, there is only one subtraction operator to shrink the histogram. Therefore, the HS method is very appropriate to hardware implementation. Compared to the PCCE algorithm [2], the HS method is automatically applied to different images without adjusting parameter, indicating that it has high potential for real-time Full-HD displays.

4. CONCLUSION

This paper has proposed the HS algorithm for emissive panels of display devices. We have formulated an objective function subject to constant entropy, which prevents distortion of image histogram after power reduction. Specifically, the HS algorithm involves one subtraction operator for computing image. Hence, it is very appropriate for real-time applications of modern Full-HD displays. For contrast enhancement, we have also employed two related HE-based algorithms. After HS is integrated into the HE-based algorithm, we demonstrate that not only power reduction but the improvement of contrast enhancement is achieved. In the future work, the efficient hardware architecture of the HS algorithm would be presented to increase performance.

5. REFERENCES

[1] T. Celik and T. Tjahjadi, “Contextual and variational contrast enhancement,” *IEEE Trans. Image Process.*, vol. 20, no. 12, pp. 3431-3441, Dec. 2011.

[2] C. Lee, C. Lee, Y.-Y. Lee, and C.-S. Kim, “Power-constrained contrast enhancement for emissive displays based on histogram equalization,” *IEEE Trans. Image Process.*, vol. 21, no. 1, pp. 80-93, Jan. 2012.

[3] S.-C. Huang, F.-C. Cheng, and Y.-S. Chiu, “Efficient contrast enhancement using adaptive Gamma correction with weighting distribution,” *IEEE Trans. Image Process.*, Digital Object Identifier: 10.1109/TIP.2012.2226047

[4] P.-S. Tsai, C.-K. Liang, T.-H. 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.

[5] 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.

[6] Y.-K. Lai, Y.-F. Lai, and P.-Y. 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.

[7] M. Dong, Y.-S. K. Choi, and L. Zhong, “Power modeling of graphical user interfaces on OLED displays,” *in Proc. Des. Autom. Conf.*, Jul. 2009, pp. 652-657.

[8] K. Panetta, E. Wharton, and S. Agaian, “Human visual system-based image enhancement and logarithmic contrast measure,” *IEEE Trans. Syst., Man, Cybern. B, Cybern.*, vol. 38, no. 1, pp. 174-188, Feb. 2008.

Fig. 3. Results of different IP algorithms; (a) original images; (b) HS; (c) CVC; (d) HS+CVC; (e) AGCWD; (f)HS+AGCWD.

Table 1. The quantitative assessment of contrast ratio using EME.

Method	Baboon	Cameraman	Clock	Einstein	Jet	Lena	Peppers	Tank
CVC	33.89	19.65	13.26	28.75	18.02	28.17	24.51	23.99
HS+CVC	34.15	24.29	14.21	29.60	18.12	28.42	24.93	24.55
AGCWD	19.88	16.86	7.09	21.99	8.90	20.75	21.92	13.75
HS+AGCWD	22.36	24.01	12.34	25.82	11.90	22.64	23.29	18.58

Table 2. The quantitative assessment of power reduction using average TDP.

Method	Baboon	Cameraman	Clock	Einstein	Jet	Lena	Peppers	Tank
CVC	128.18	124.85	177.95	115.62	164.97	110.96	124.34	137.41
HS+CVC	124.39	120.65	161.90	101.71	154.87	109.31	122.74	130.31
AGCWD	176.95	161.49	211.81	158.57	213.44	144.60	162.84	186.37
HS+AGCWD	171.89	156.94	198.01	140.42	204.17	142.34	160.82	169.44