Power-Constrained Image Processing Techniques for Emissive and Non-Emissive Displays

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Keywords: ***Low power image processing, histogram equalization***

Abstract

Power-constrained image processing techniques for emissive and non-emissive displays are proposed in this work. First, we develop a power consumption model and an image quality loss metric for each display. Then, we integrate those terms into histogram equalizing equation to formulate an objective function. By minimizing the objective function, the proposed algorithm achieves contrast enhancement and power saving simultaneously. Simulation results demonstrate that the proposed algorithm improves image quality under the low power conditions.

1. Introduction

The rapid development of imaging technology has empowered even mobile devices to take and process digital photographs. Since lighting conditions and image acquisition system are not ideal, we often obtain low quality photographs. Various techniques have been proposed to improve the qualities of acquired images. Many contrast enhancement techniques have been developed. Histogram equalization (HE) is one of the most widely adopted approaches to enhance low contrast images, which attempts to make the histogram of light intensities of pixels within an image as uniform as possible [1]. Due to its simplicity and effectiveness, HE is employed in various applications of image processing.

Whereas a variety of HE techniques have been proposed for the contrast enhancement of general image, relatively little effort has been made to adapt the enhancement process to the characteristics of display devices. A large portion of power is consumed by display panels in mobile devices [2]. Since power saving is an important issue for electrical devices especially in mobile environments, it is essential to develop an image processing algorithm, which can save power in display panels as well as enhancing image contrast.

In this work, we propose power-constrained image processing techniques for emissive and non-emissive displays based on HE. We make a power consumption model and a quality loss metric for each device. Then, we integrate those terms into histogram equalizing equation to develop an objection function. The output transformation function is obtained by minimizing the objective functions. Simulation results show that the proposed algorithm provides good perceptual image quality, while reducing power consumption.

2. Histogram Equalization

HE enhances the dynamic range of an image and yields good perceptual image quality. However, if many pixels are concentrated within a small range of gray levels, the output transformation function may have an extreme slope. This causes severe degradations on the output image. Therefore, we should suppress extreme peak values in the input histogram, which produces steep slopes in the transformation function. The proposed algorithm is based on the modified histogram equalization which relaxes extreme histogram values by weighted averaging uniform histogram [3]. According to notations in [4], the transformation function $\mathbf{x}$ is obtained by minimizing

$$C_i = ||\mathbf{D}\mathbf{x} - \left(\alpha\overline{\mathbf{h}} + (1-\alpha)\mathbf{u}\right)/2||^2 \quad (1)$$

where $\overline{\mathbf{h}} = 255 \cdot \mathbf{h}/(\mathbf{1}^t\mathbf{h})$ is normalized histogram $\mathbf{h}$ and $\mathbf{u}$ is uniform histogram whose elements are all $1/255$. $\mathbf{D}$ is differential matrix [4], and $\alpha \in [0,1]$ is a user-controllable parameter.

3. Proposed Image Processing Technique for Emissive Displays

The power consumption of emissive displays is proportional to the square of input pixel intensity [4]. By adding the power consumption term to the initial objective function in (1), we obtain new transformation function $\mathbf{x}$, which minimizes

$$C_e = C_i + \lambda\mathbf{x}^t\mathbf{H}\mathbf{x} \quad (2)$$

where λ is a user parameter balancing between power and contrast. If $\lambda = 0$, the power saving is not considered. On the other hand, as λ increase, the output image gets darker to achieve power reduction.

4. Proposed Image Processing Technique for Non-Emissive Displays

Conventional low power image processing techniques for

(a) (b)

Fig. 1. Comparison of the processed images at the same power: (a) linear scaling and (b) the proposed algorithm.

non-emissive displays compensate a reduced backlight by increasing pixel intensities. Let us denote backlight scaling factor as $b \in [0,1]$. Then, output pixel intensities are scaled by factor of $1/b$. Since the maximum values are limited to dynamic range, the display shows $\min(255, \mathbf{x}/b)$. Therefore, the amount of quality loss at each grey level is given by

$$\mathbf{x}_b = \min\left(0, \min(255, \mathbf{x}/b) - 255\right) \quad (3)$$

The quality loss when $\mathbf{x}$ from (1) is applied to the input image is modeled by $\mathbf{x}_b^t \mathbf{H} \mathbf{x}_b$, where $\mathbf{H}$ is the diagonal matrix form of the input histogram $\mathbf{h}$. By integrating this term into initial objective function (1), we obtain

$$C_n = C_i + \mu \mathbf{x}_b^t \mathbf{H} \mathbf{x}_b \quad (4)$$

where μ is a user-controllable parameter.

4. Simulation Results

We evaluate the performance of the proposed algorithm on various test images. Fig. 1 compares the linear reducing method with the proposed algorithm at the same power consumption. Images on the left look hazy because of low contrast. On the other hand, the proposed method provides more satisfactory image quality.

Fig. 2 shows the result when the proposed algorithm for non-emissive displays is applied. In case of the linear mapping, details in bright regions are lost. Although the conventional algorithm [2] preserves the detail, the dynamic range is reduced and noise pixels are amplified. The proposed algorithm shows better image quality.

(a) (b) (c) (d)

Fig. 2. Comparison of result image when the backlight compensation is applied with $b = 0.7$. (a) input image, (b) linear compensation, (c) the conventional algorithm [2], (d) the proposed algorithm.

4. Conclusions

In this work, we proposed the power-constrained image processing algorithms, which can enhance image quality and reduce power consumption. Based on the modeling of power consumption and quantative image quality loss, we developed the objective functions, and otbained transformation functions which produce visual pleasing results.

Acknowledgment

This research was supported by Basic Science Research Program through the National Research Foundation of Korea (NRF) funded by the Ministry of Education, Science and Technology (2011-0001271).

References

1. R. C. Gonzalez and R. E. Woods, *Digital Image Processing*, 3rd ed. Prentice Hall, 2007
2. 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, pp. 574-584, Apr. 2009.
3. T. Arici, S. Dikbas, and Y. Altunbasak, “A histogram modification framework and its application for image contrast enhancement,” *IEEE Trans. Image Process.*, vol. 18, pp. 1921-1935, Sep. 2009.
4. C. Lee, C. Lee, and C.-S. Kim, “Power-constrained contrast enhancement for OLED displays based on histogram equalization,” in Proc. *IEEE ICIP*, Sep. 2010.