Power Saving on Mobile Devices Through Contrast-Aware Backlight Control

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Abstract— **Based on the high penetration rate of mobile devices, reducing power consumption for mobile devices have become increasingly important. In current technology, statistics show that the display of the mobile device dominates the major power consumption of the device (e.g., up to 40% of the total power). Therefore, to efficiently reduce the display power consumption while maintaining the image quality, this paper proposes a novel contrast-aware backlight control algorithm for mobile devices. By transforming the color space for a displayed image from RGB (red, green, blue) to HSI (hue, saturation, intensity), we first calculate the RMS (root mean square) contrast for the image. Then we estimate the "brightness factor" for adjusting the image based on the RMS contrast and the employed HVS (human vision system)-based visual quality assessment technique. At the same time, the estimated brightness factor is used to determine the screen backlight brightness value of the device. As a result, the best tradeoff between the image display quality and the power consumption can be achieved. Our experimental results have demonstrated that 10~40% reduction of backlight brightness can be achieved, resulting in power consumption of 8~25%, while good image display quality can be maintained.**

I. INTRODUCTION

With the increasing popularity of mobile devices, such as smartphones and tablet computers, power saving has become a critical issue in energy consumption of mobile devices. On the other hand, with the rapid growth of Internet applications with multimedia data, most user behaviors on mobile phones have focused on browsing photos, viewing videos, and playing online games. Therefore, maintaining good visual quality while preserving battery lifetime for mobile devices has been an important research problem. To cope with this problem, researchers have investigated various low-power consumption approaches in different viewpoints of the material of screen, display technology, and design of processor, such as optimal code layout [1] and efficient circuit design [2]–[3] techniques.

Recently, power saving for mobile devices via backlight control has been shown promise based on the fact that the power consumption of the display for a device dominates the major power consumption of the device, especially for large or high-resolution screen [4]. Various approaches have been proposed for reducing power consumption while enhancing image display quality. For example, an adaptive dimming technique to reduce backlight power consumption and enhance image contrast for global backlight applications was presented in [5], where the backlight-dimming algorithm achieved 0% to 50% backlight power reduction depending on the characteristics of image data. In addition, a backlight dimming algorithm was proposed in [6] to reduce power consumption of backlight and improve image quality in LCD applications based on the brightness modulation of backlight and pixel compensation. Moreover, based on content analysis, a backlight-dimming algorithm with image contrast enhancement using histogram analysis was proposed in [7]. Furthermore, a dynamic backlight control algorithm is proposed in [8] to adjust backlight luminance for local dimming of LCD devices based on the PSNR (peak signal-to-noise ratio) metric used to guarantee the quality of displayed image. On the other hand, a contents-adaptive backlight control method was proposed in [9] by jointly considering both image quality and power consumption. The region of interest (ROI) is detected for an image, where the three attributes including entropy, luminance, and saturation information for ROI are extracted. Then, optimal value of backlight can be calculated by a linear combination of these attributes.

Most of the existing approaches may suffer from some disadvantages: *1)* only focusing on the reduction of power consumption without sufficiently considering the quality of displayed images; *2)* may induce visible or serious image distortions; or *3)* the degree of overall power reduction is not significant enough. Therefore, in this paper, as shown in Fig. 1, a novel contrast-aware backlight control algorithm for mobile devices is proposed to reduce the power consumption while maintaining the displayed image quality. The main contribution of this paper is three-fold: *1)* the proposed method is based on HVS-based visual quality assessment to ensure that the produced display images are acceptable to human vision; *2)* the proposed method can not only reduce power consumption of mobile devices, but also maintain good

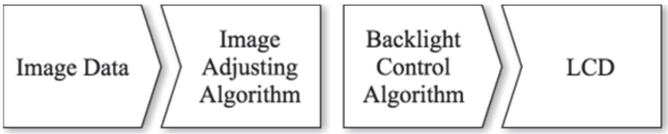


Fig. 1. Block diagram of the proposed Contrast-Aware Backlight Control framework for mobile devices.

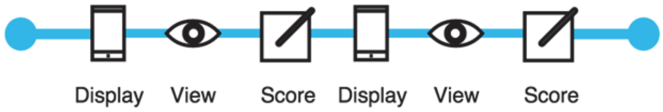


Fig. 2. The ACR5 subjective image quality assessment process.

display quality; and *3)* the proposed algorithm is extremely efficient, which is low-power-consuming and suitable to battery-powered mobile devices.

The rest of this paper is organized as follows. In Sec. II, we provide a brief overview of the employed HVS-based visual quality assessment technique. Sec. III details the proposed approach. Sec. IV reports and discusses the experimental results. Conclusions are drawn in Sec. V.

II. Visual Quality Assessment via ACR5

In this section, the ACR5 visual quality assessment technique used in the proposed method is briefly introduced. The ACR (absolute category rating) method [10] addressed in the ITU-T recommendation P.910 is a subjective assessment method for multimedia quality evaluation, which has been one of the most widely used methods for assessing the quality of telecommunication services. ACR is a category judgment method where the test images/videos are presented one at a time and are rated independently on a category scale. As shown in Fig. 2, In the ACR method with five-grade quality scale (denoted by ACR5), the subjects watch the assessment image for about 10 seconds, and during the subsequent interval of up to 10 seconds, they assess the image on the five-grade quality scale. That is, the five scales are denoted by 5 (excellent), 4 (good), 3 (fair), 2 (poor), and 1 (bad), which, respectively, represent the preference levels of visual quality. In the assessment results, the number of votes by the subjects in each category is weighted by the assessment scores and expressed as a mean opinion score (MOS). The test process will be repeated until the last test image is assessed.

III. Proposed Contrast-Aware Backlight Control Algorithm

Roughly speaking, as illustrated in Fig. 3 (similar to [4]), the basic idea of the proposed contrast-aware backlight control framework is to enhance the brightness of an image to be displayed on a device while dimming the brightness of the backlight for the screen of the device. The major goal is to provide acceptable visual quality while reducing the power consumed by the screen of the device. In this section, we first address the problem formulation of this paper, followed by presenting the details of the proposed algorithm.

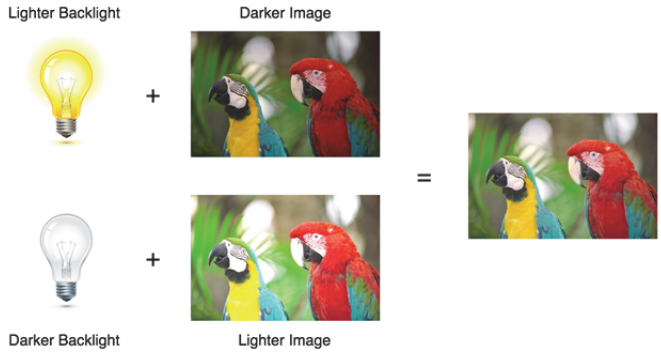


Fig. 3. Illustration of the basic idea of the proposed contrast-aware backlight control framework.

A. *Problem formulation*

For efficiently displaying an image on a LCD screen of a mobile device while achieving the best tradeoff between the image quality and the power consumption, we formulate the problem as:

$$\begin{bmatrix} R \\ G \\ B \end{bmatrix} = k \times \begin{bmatrix} R_0 \\ G_0 \\ B_0 \end{bmatrix}, \quad (1)$$

where $\left[R_0, G_0, B_0\right]^T$ denotes the original image $I_{original}$ to be displayed in the RGB color space. (R_0, G_0, B_0) denotes the set of RGB pixel values of $I_{original}$, $\left[R, G, B\right]^T$ similarly denotes the adjusted image $I_{adjusted}$ of $I_{original}$, *i.e.*, the final displayed image, and k (≥ 0) is the brightness factor to be solved. The factor k will be not only used to adjust the image to be displayed, but also used to calculate the backlight brightness of the screen for a mobile device.

B. *Image analysis*

To properly adjust the brightness of an image to be displayed, it is straightforward to analyze the contrast of the image first. For jointly considering the computational complexity to analyze the contrast of the image, in this study, we calculate the root mean square (RMS) contrast value for the image $I_{original}$ as the standard deviation of the image pixel intensities by:

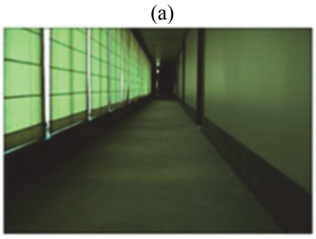
$$C_{RMS} = \sqrt{\frac{1}{WH}\sum_{i=0}^{W-1}\sum_{j=0}^{H-1}(I_{ij} - \bar{I})^2}, \quad (2)$$

where W and H represent the width and height of the image $I_{original}$, respectively, I_{ij} indicates the intensity (or brightness) value of the (i, j)-th pixel of the image, and $\bar{I}$ means the average value of all pixel intensity values of the image.

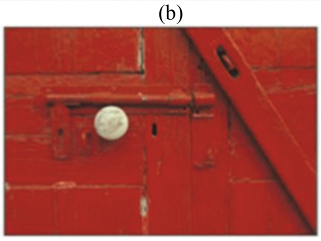
To calculate the intensity value for each pixel in the image $I_{original}$, we first convert the color representation of the image

(a)

(b)



(c)



(d)

Fig. 4. Four test images used by the experiments of subjective quality assessment for exploring the relationship between the subjective visual experiences and the brightness factors on different backlight levels.

from the RGB to HSI color spaces to get the intensity value for each pixel by:

$$I_{ij} = \frac{\left(R_0 + G_0 + B_0\right)_{ij}}{3}, \tag{3}$$

where I_{ij} is defined in (2), and $\left(R_0 + G_0 + B_0\right)_{ij}$ denotes the R, G, B color values of the (*i*, *j*)-th pixel of the image $I_{original}$.

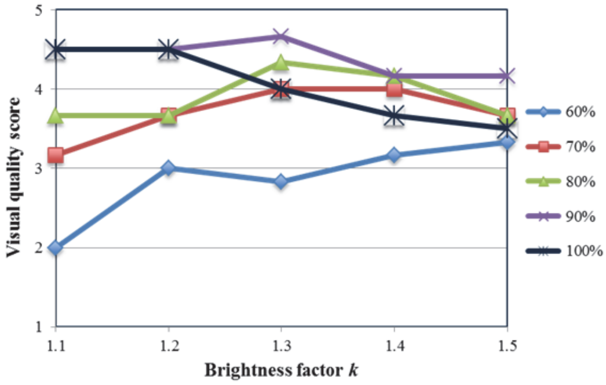
C. Subjective image quality assessment

To support our basic idea of the proposed contrast-aware backlight control framework illustrated in Fig. 3, we first conduct the experiments on subjective visual quality assessment via ACR5 [10]. The main goal of this subjective study is to explore the relationship between the subjective visual experiences (average visual quality scores given by the subjects, ranged from 1 to 5) and the brightness factors (*k*) on different backlight levels (%). In our experiments, six subjects were invited to see the four test images (shown in Fig. 4) and give their scores based on ACR5. In Fig. 4, two of the four test images are with high contrast (Fig. 4(a) and Fig. 4(b)), while the others are with low contrast (Fig. 4(c) and Fig. 4(d)).

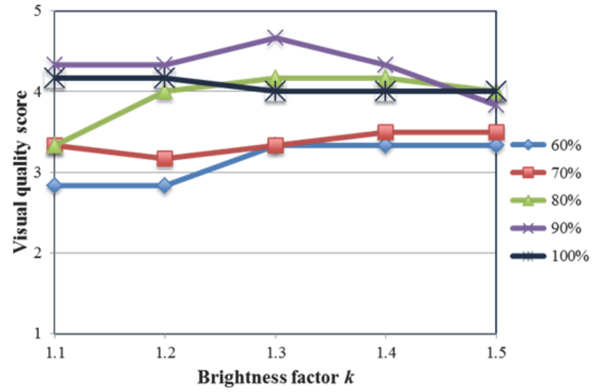
Based on the subjective visual quality assessment results shown in Fig. 5, it can be roughly observed when the backlight is darker (brightness level (%) is lower), the visual quality score will increase with increasing the brightness (*k*) of the image. On the other hand, when the backlight is lighter (brightness level (%) is higher), the visual quality score will increase with decreasing the brightness (*k*) of the image. Moreover, we also observed if $k \geq 1.5$, the image will be too bright, while if $k \leq 0.05$, the visual qualities of these test images will be unacceptable. Therefore, in the proposed algorithm, *k* is empirically set to from 1.1 to 1.5

D. Image enhancement with backlight control

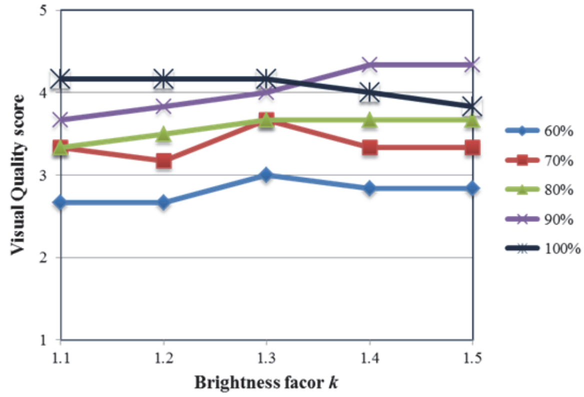
Based on the subjective visual quality assessment results on different backlight levels, *k* can be defined as:



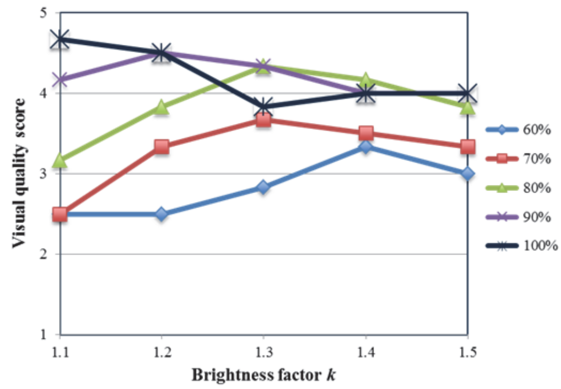
(a)



(b)



(c)



(d)

Fig. 5. The subjective visual quality assessment results shown from top to down denote the results corresponding to the test images, Fig. 4(a), Fig. 4(b), Fig. 4(c), and Fig. 4(d).

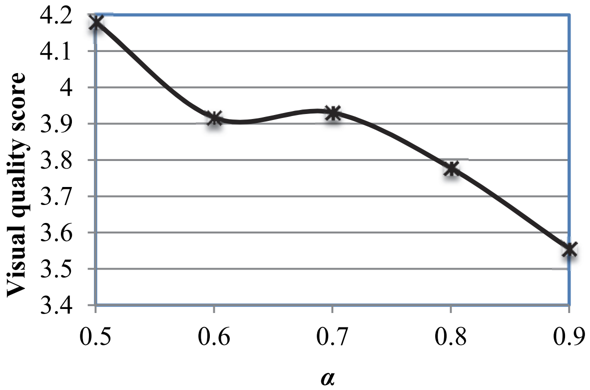


Fig. 6. Determination of the influent ratio *α* for calculating the brightness factor *k*.

$$k = 1 + \alpha \frac{C_{RMS}}{128}, \tag{4}$$

where C_{RMS} denotes the root mean square contrast value for the image $I_{original}$ (defined in (2)), and α denotes the "influent ratio" of the contrast, determined via the subjective visual quality assessment, described later.

After adjusting the image to be displayed based on the brightness factor (k) and (1), the brightness factor is used to determine the backlight level (or dimming level) for the screen of the device. Based on [11], the backlight brightness is determined by the square root of average intensity of an input image. However, based on our experiment that as we adjust the image and combine it with the backlight algorithm associated with the root of average intensity of the image just like,

$$Backlight = \frac{\sqrt{\bar{I}_{orignal}}}{\sqrt{\bar{I}_{adjusted}}} \times 100\% = \frac{1}{\sqrt{k}} \times 100\%, \tag{5}$$

the display image will be too bright. On the other hand, based on our evaluations, we find out that the backlight brightness determined by the square of average intensity of the input image will induce better performance. Therefore, in our method, the backlight brightness level is defined as:

$$Backlight = \left(\frac{\bar{I}_{orignal}}{\bar{I}_{adjusted}} \right)^2 \times 100\% = \frac{1}{k^2} \times 100\%, \tag{6}$$

where $\bar{I}_{original}$ and $\bar{I}_{adjusted}$ denote the average intensity values of the pixel intensities in $I_{original}$ (original image) and $I_{adjusted}$ (adjusted image), respectively. When C_{RMS} equals to 0, k will be 1, and the image to be displayed and the backlight of screen will be kept unchanged.

In addition, to decide the value of the influent ratio α, similar to the conducted experiments of subjective visual quality assessment described in Sec. III-C, we conducted the experiments by choosing different α values ranged from 0.5 to 0.9. Based on Fig. 6, we find that when α is set to 0.5, the good visual quality performance (over score 4) can be achieved and the value of k won't be too small to save power. Therefore, α will be empirically set to 0.5 in the further experiments described in Sec. IV.

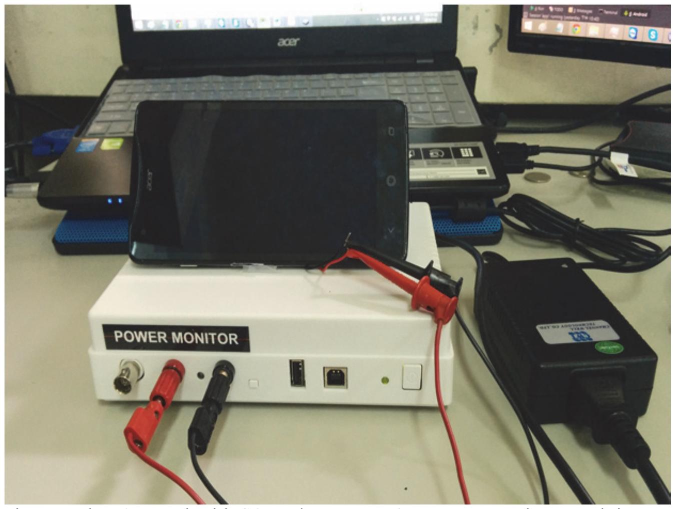


Fig. 7. The Acer Liquid S1 and Monsoon's power monitor used in our experiments.

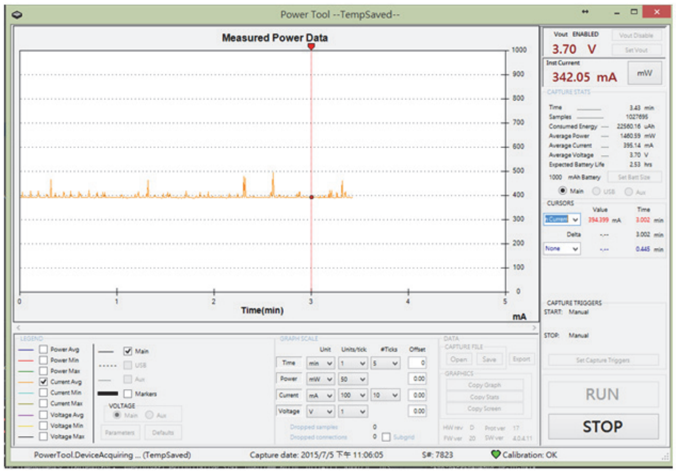


Fig. 8. Displayed results of the power measurement.

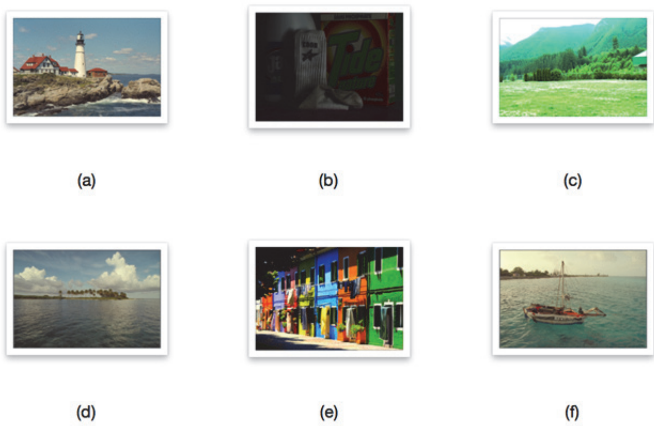


Fig. 9. Six test images.

IV. Experimental Results and Discussions

To evaluate the performance of the proposed contrast-aware backlight control algorithm, we implemented the method on the mobile device of Acer Liquid S1 with 5.7 inch of 1280×720 screen, 4 core 1.5Ghz CPU, and the Android 4.2 operating system. In addition, the employed power measurement device in our experiment was Monsoon's power monitor, which can measure the instant power cost during the period that the device is working. Moreover, the battery of the mobile device was modified to be connected to the power monitor. The working environment is shown in Fig. 7 and the measurement results were displayed on the computer screen during the experiment, as shown in Fig. 8.

The six test images shown in Fig. 9 were used to measure the power consumption. These images are with different characteristics that can make the test more comprehensive. More specifically, Figs. 9(a) and 9(f) are with high complexity and low complexity of image contents, respectively. Figs. 9(b) and 9(c) are with low luminance and high luminance, respectively. Figs. 9(d) and 9(e) are with low contrast and high contrast, respectively. Table 1 lists the values of C_{RMS}, k, the backlight brightness, and the backlight reduction percentage for the six test images, respectively. Based on the experimental results of power consumption measurement shown in Tables 2 and 3, it can be observed that the proposed method can save 100~350mW in power consumption, which is approximately 8~25% of the total power consumption for the mobile device. Besides, the average visual quality assessment score of the six test images after adjusted is over 4, which means a good visual display quality has been maintained.

V. CONCLUSIONS

In this paper, we have proposed a power saving method for mobile devices through contrast-aware backlight control. The proposed method can simultaneously achieve low power consumption and satisfactory image display quality. The experimental results have demonstrated that our method can decrease 10~40% of the backlight brightness while reducing approximately 8~25% of the total power consumption. In addition, the larger the mobile device's screen is, the more energy will be saved via our power saving method.

Comparing with other method, our algorithm is simple and with good computational efficiency. Besides, although our saving percentage seems to be less than [5]'s 0~50%, or [6]'s 14%~43%, our saving percentage is of the total power consumption for the mobile device, different from their saving percentages are only of the backlight power consumption. As the denominator becomes smaller and the numerator remains unchanged, the saving percentage will undoubtedly become larger. Therefore, our performance on saving power is still quite competitive.

For future works, more factors, such as computational complexity and different influences on human eyes of different colors, will be investigated to improve the performance in terms of better visual quality and lower power consumption. Furthermore, we will also apply this method extensively for display videos on mobile devices, such as [12], where our method would lean more toward frame adjusting, instead of frame skipping.

Table 1. The values of C_{RMS}, k, the backlight brightness, and the backlight reduction percentage for the six test images.

	C_{RMS}	k	Backlight	Backlight Reduction
Fig. 9(a)	43.7789	1.171	185/255	27.45%
Fig. 9(b)	20.1651	1.079	219/255	14.12%
Fig. 9(c)	56.3042	1.220	171/255	32.94%
Fig. 9(d)	41.5248	1.162	188/255	26.27%
Fig. 9(e)	76.0272	1.297	151/255	40.78%
Fig. 9(f)	49.5944	1.194	178/255	30.20%

Table 2. Measured data of power consumption.

	Original image	Adjusted image
Fig. 9(a)	1460.59 mW	1242.40 mW
Fig. 9(b)	1423.08 mW	1310.19 mW
Fig. 9(c)	1484.11 mW	1209.13 mW
Fig. 9(d)	1460.60 mW	1246.87 mW
Fig. 9(e)	1489.96 mW	1112.69 mW
Fig. 9(f)	1473.84 mW	1224.80 mW

Table 3. Reductions of power consumption.

	Reduction	Percentage
Fig. 9(a)	218.19 mW	14.94%
Fig. 9(b)	112.89 mW	7.93%
Fig. 9(c)	274.98 mW	18.53%
Fig. 9(d)	213.73 mW	14.63%
Fig. 9(e)	377.27 mW	25.32%
Fig. 9(f)	249.04 mW	16.90%

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