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Reduction of quantization errors caused by dynamic LCD backlight scaling

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Abstract: Dynamic backlight scaling (DBS), a technique for LCD power reduction, often deteriorates image quality because of a flicker (unintended temporal variation of the luminance) generated in the frame at which the backlight level changes. This paper proposes a novel DBS algorithm to reduce the flicker by decreasing the quantization errors (QEs) that are created in the multiplication of the input gray level and the DBS scaling ratio as well as in the mapping of the multiplication result to an integer gray level. The proposed DBS algorithm reduces the QE down to 28.8% when compared with the conventional DBS algorithm.

Keywords: LCD, backlight scaling, quantization error reduction

Classification: Electronic displays

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1 Introduction

To reduce the power dissipated by the backlight of an LCD, DBS [1, 2, 3]

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decreases the voltage level applied to the backlight and increases the transmittance of the panel to compensate for the decreased backlight level. If the increased transmittance does not exactly match the decreased backlight, the output luminance is different from the target luminance. This difference is called a distortion and extensive effort has been made to reduce the distortion [1, 2, 3]. A flicker is another source of quality degradation caused by DBS. In initial research for flicker reduction, the distortion is regarded as the main cause of the flicker [1, 2]. However, even with the image without much distortion, a flicker still is observed. Thus, this paper investigates another cause of a flicker and pays attention to the quantization error (QE) in the transmittance calculation. In general, the transmittance level accepted by an LCD panel is an integer from 0 to 255. However, the exact transmittance level for DBS is a real number (see details in Section 2). The QE is caused by the difference between the desired transmittance in a real number and the panel input transmittance in an integer number. The effect of a QE on the image quality is important because the QE is included in most pixels, so that it is observed in wide regions although the magnitude of the QE for each pixel is small. Moreover, the temporal luminance variation is easily perceived by human visual system (HVS).

This paper investigates the reduction of the flicker caused by a QE when DBS is used for LCD power reduction. There exist two sources of QEs. First, a QE is created in the multiplication of an input gray level and the DBS scaling ratio which must be quantized as an input to a fixed-point multiplier. To reduce the QE, ordered dithering [7] is applied to the quantization. Another QE is created when the multiplication result is mapped to a gray level which is an integer between 0 and 255. To reduce this QE, Floyd-Steinberg error diffusion [8] is used. As a result of error diffusion, the error between the original tone level and the transformed tone level is distributed into the neighboring pixels, so that the difference of the original image and the error diffused image is less visible. Experimental results show that the QE is reduced to 28.8% by the proposed techniques when compared with the conventional DBS algorithm.

2 Dynamic backlight scaling

Let i denote an input gray level to an LCD panel and $t(i)$ denote the transmittance of the panel for the input level i. Then, $t(i)$ is implemented as follows:

$$t(i) = i^{\gamma} \tag{1}$$

where γ ranges from 2.2 to 2.5. Let $L(i)$ denote the output luminance of an LCD panel. Then, $L(i)$ is proportional to the transmittance.

$$L(i) = K \cdot t(i) \tag{2}$$

where K is a constant. Let $L_{DBS}(i)$ denote the luminance of an LCD when DBS is applied. Then, $L_{DBS}(i)$ is expressed as follows:

$$L_{DBS}(i) = K \cdot \beta \cdot t(p(\beta \cdot i)) \tag{3}$$

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where β denotes the decreased backlight illumination ranging from 0 to 1. $p(\beta, i)$ is the pixel transformation function that increases the input gray level compensating for the decreased backlight. When β becomes less than 1, $p(\beta, i)$ must be greater than i to make $L_{DBS}(i)$ equal to $L(i)$, i.e., $L_{DBS}(i) = L(i)$. To make $L_{DBS}(i) = L(i)$, $p(\beta, i)$ is derived as $(1/\beta)^{1/\gamma} \times i$ where $(1/\beta)^{1/\gamma}$ represents the scaling ratio of the input gray level and is denoted by ρ, i.e., $\rho = (1/\beta)^{1/\gamma}$.

Let i_{DBS} denote the input gray level that generates the output luminance level of $L_{DBS}(i)$ without DBS. From (3),

$$i_{DBS} = (1/K)^{1/\gamma} \cdot L_{DBS}(i)^{1/\gamma} \tag{4}$$

Thus, the gray level error equivalent to the luminance error is given by

$$i_{error} = i - i_{DBS} \tag{5}$$

3 Quantization error reduction

Fig. 1 shows the proposed DBS procedure. In this figure, i(x, y) denotes the input gray level of pixel (x, y). For a given β, ρ is first derived. Note that ρ is a real number and it must be rounded off for multiplication. Ordered dithering [4] is employed to reduce the QE caused by the round-off. To reduce the precision of the multiplier, certain LSBs (Least Significant Bits) of ρ are rounded off and then the remaining MSBs (Most Significant Bits) are used as the input to the multiplier. Let $lsb(\rho)$ denote the LSBs of ρ that are to be rounded off and $msb(\rho)$ denote the MSBs that are used as the input. The ordered dithering compares $lsb(\rho)$ with the 4x4 Bayer ordered dither matrix element and either $msb(\rho)$ or $msb(\rho) + 1$ is selected as the input to the multiplier.

$$Multiplier\ input = \left\{ \begin{array}{ll} msb(\rho), & lsb(\rho) > D_4[x \bmod 4, y \bmod 4], \\ msb(\rho) + 1, & otherwise, \end{array} \right\} \tag{6}$$

where D4 is a 4x4 matrix with its entries [0, 8, 2, 10; 12, 4, 14, 6; 3, 11, 1,

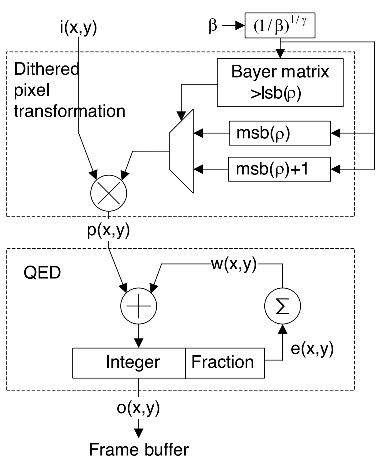

Fig. 1. Proposed DBS algorithm.

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9; 15, 7, 13, 5]. The operation of (4) is calculated in advance and stored in a ROM, so that (6) is performed by ROM read operations.

Before p(x, y) is rounded off, p(x, y) is added to w(x, y) which is the weighted sum of round-off errors propagated from neighboring pixels. Then, the final outcome of the DBS algorithm, denoted by o(x, y), is obtained by rounding off the summation of p(x, y) and w(x, y).

$$o(x,y) = round - off(p(x,y) + w(x,y)). \tag{7}$$

The QE denoted by e(x, y) is the round-off error

$$e(x,y) = p(x,y) + w(x,y) - o(x,y). \tag{8}$$

The error e(x, y) is propagated to the neighboring pixels and the sum of the propagated errors in (8) is obtained by

$$\begin{aligned} w(x,y) = (&1 \cdot e(x-1,y-1) + 5 \cdot e(x,y-1) + 3 \cdot e(x+1,y-1) \\ &+ 7 \cdot e(x-1,y))/16. \end{aligned} \tag{9}$$

Equation (9) is the Floyd-Steinberg algorithm which is one of the widely used algorithms for error diffusion [5].

4 Simulation results

For evaluation, Foreman, Mobile and calendar, Hall monitor, Coastguard, and Table tennis sequences in the RGB format are used. The conventional DBS algorithm and the proposed DBS algorithm are implemented in C program and the amount of QE is compared. All variables and intermediate results are stored in a fixed-point format such that 8, 8, 10, 4 and 2 bits are assigned to i(x, y), o(x, y), p(x, y), w(x, y), and e(x, y), respectively.

A flicker may be easily observed when consecutive frames have different luminance errors. Thus, the mean of temporal error between consecutive frames is defined as follows:

$$MTE = \frac{1}{X \cdot Y} \sum_{y=1}^{Y} \sum_{x=1}^{X} (i_{error}(x,y,t) - i_{error}(x,y,t-1)) \tag{10}$$

where $X \cdot Y$ is the image size and $i_{error}(x,y,t)$ is the error between the target gray level and the displayed gray level distorted by DBS at pixel (x, y) and at frame t. MTE is the average difference of the errors of the same pixel in the current and previous frames.

Fig. 2 shows the MTE variation over 300 frames. The MTEs with the conventional DBS and the proposed DBS are shown in Fig. 2 (a) and (b), respectively. In Fig. 2 (a), a very large MTE is observed when β is changed. In Fig. 2 (b), the amount of MTE is much smaller than that in Fig. 2 (a).

Table I shows the MTE averaged over 300 frames of each sequence. On average, the proposed algorithm reduces the MTE from 0.312 to 0.090 which is only 28.8% that of the conventional DBS.

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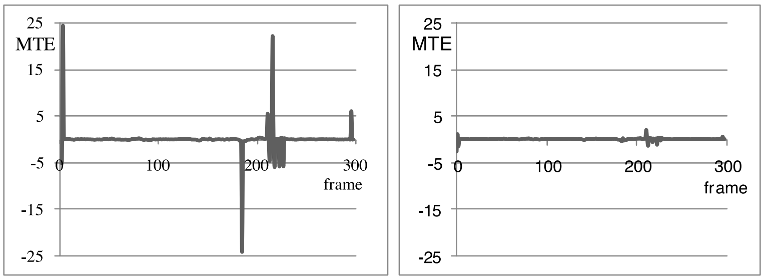

(a) Conventional DBS (b) Proposed DBS

Fig. 2. MTE comparison.

Table I. MTE averaged over 300 frames.

	Conventional DBS	Proposed DBS
Foreman	0.463	0.084
Mobile and calendar	0.146	0.029
Hall monitor	0.189	0.040
Coastguard	0.390	0.162
Table tennis	0.374	0.136
Average	0.312	0.090

5 Conclusion

The main contribution of this paper is the finding of the QE as the source of a flicker when DBS is applied to LCD display. This paper proposes a new technique to reduce the QE. Ordered dithering is used to reduce the QE when the DBS scaling factor is used as the input to a fixed point multiplier. Then, error diffusion is used to reduce the QE when the multiplication result is used as the input gray level. With five video sequences, the QE is reduced to 28.8% with the proposed DBS.

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