QUASI-BI-QUADRATIC INTERPOLATION FOR LUT IMPLEMENTATION FOR LCD TV

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Keywords: LCD, LUT, Interpolation, Overdrive, Quadratic function.

Abstract: Overdriving schemes are used to improve the response time of LCD (Liquid Crystal Display). Typically they are implemented by using LUT (Look-Up Table) within an image processor. However, the size of LUT is limited by the physical memory size and system cost. In actual implementation of LUT, final overdriving values are obtained using interpolation methods. However, interpolation errors may cause some display artifacts and response time delay. In this paper, we present an improved method for LUT implementation using linear interpolation and piecewise least-square polynomial regression to reduce such errors. The proposed method improves LUT performance with reduced memory requirements.

1 INTRODUCTION

Recently, the demand for TFT LCD-TVs has dramatically increased. TFT-LCD TVs have many advantages including high resolution, light weight, slim size and low power consumption. On the other hand, there are also some problems such as slow response time. Response time is very important for LCD TVs since TV monitors need to properly display moving pictures (Song et al., 2004). The overdrive technique improves the response time of TFT-LCDs by enlarging the desired change in the pixel value to force LC materials (Wubben et al, 2004, Someya et al., 2003, Hartman et al., 1996, Lee et al, 2001, K. Kawabe and T.Furuhashi, 2001). A block diagram of overdrive is shown in Figure 1.

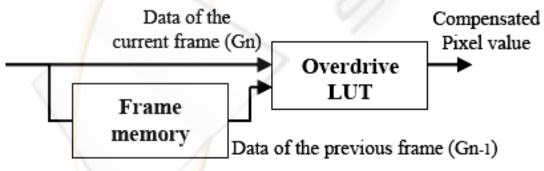

Figure 1: Block Diagram of overdrive.

The overall system includes a signal processing unit which generates a current frame data, a frame memory to store a previous frame data, an overdriving unit to generate the current frame data using the frame memory and the look-up table (LUT), and a liquid crystal panel configured to display the frame data.

For each pair of the pixel value of the current frame and the pixel value of the previous frame, the look-up table (LUT) is used to compute a compensated value based on TFT-LCD response time characteristics. However, most LUT stores a part of the entire LUT data (256x256 matrix) since the LUT size is limited by the physical memory size and fabrication cost. For example, a typical LUT has 8 x 8 matrix format and final overdriving pixel values of LUT are computed using an interpolation method. In generally, bilinear interpolation is used due to its simple implementation. However, bilinear interpolation may introduce artifacts. In this paper, we propose a new interpolation method for this LUT implementation.

2 LUT FOR OVERDRIVE

A complete LUT requires a 256x256 matrix structure in an 8-bit overdrive scheme. A total of 256x256 LUT values are needed for all possible combinations of current and previous gray levels and optimum LUT values for overdrive are determined by experimental measurements. Figure 2 and Figure 3 show the characteristics of typical LUT data. As can be seen in the Figure 2, the LUT column data has non-linear characteristics. However, the LUT row data (Figure 3) shows more linear

Park H., Seo G. and Lee C. (2009).
QUASI-BI-QUADRATIC INTERPOLATION FOR LUT IMPLEMENTATION FOR LCD TV.
In *Proceedings of the First International Conference on Computer Imaging Theory and Applications*, pages 70-73
DOI: 10.5220/0001807600700073

characteristics than the LUT column data. In bilinear implementation, missing values are interpolated using linear functions. When three data points are available, one can use a quadratic interpolation function:

$$f(x) = a_0 + a_1 x + a_2 x^2 .$$

The three coefficients can be determined from the three data points and this quadratic function can be used to fill in missing values between the three points. We will call this method the quadratic interpolation method.

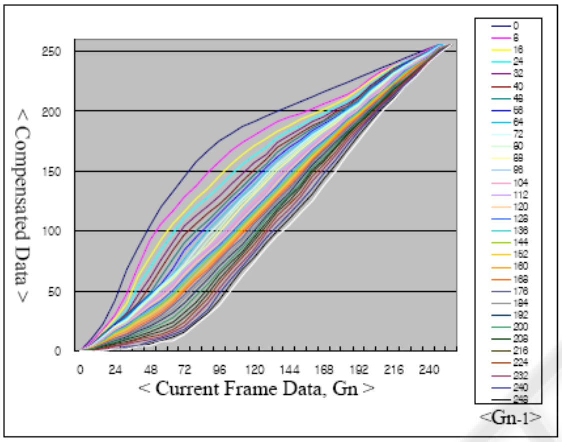

Figure 2: LUT column data.

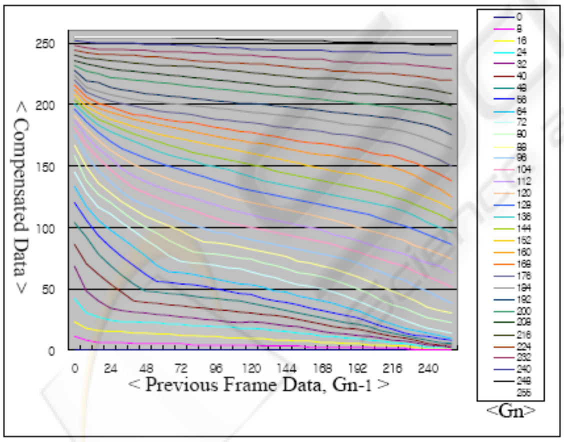

Figure 3: LUT row data.

3 THE PROPOSED ALGORITHM

In the proposed method, linear interpolation and least-square regression methods are used for LUT implementation. It can be seen that the column data of LUT (Figure 2) shows more non-linear characteristics than the row data of LUT (Figure 3). Based on these observations, we propose to use a quadratic regression method to find the best-fit of the column data of LUT and to use linear interpolation for the row data of LUT. The proposed quasi-bi-quadratic interpolation is illustrated in Figure 4.

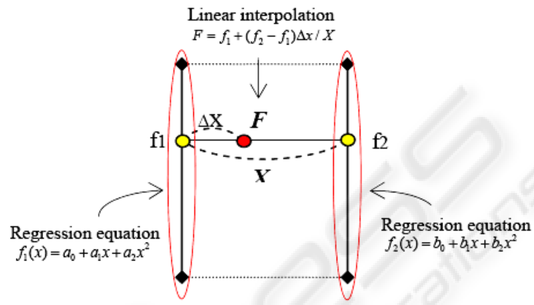

Figure 4: Concept of quasi-bi-quadratic interpolation.

In the proposed method, f1 and f2 are first computed using quadratic polynomials.

$$f_1(x) = a_0 + a_1 x + a_2 x^2 \tag{1}$$

$$f_2(x) = b_0 + b_1 x + b_2 x^2 \tag{2}$$

To obtain the coefficients, the least square method is used:

$$y = a_0 + a_1 x + a_2 x^2 + e \tag{3}$$

where e is an error. Then, we can compute S_r which is the square sum of error e as follows:

$$S_r = \sum_{i=1}^{n} e_i^2 = \sum_{i=1}^{n} (y_i - a_0 - a_1 x_i - a_2 x_i^2)^2 \tag{4}$$

To find a_0, a_1, a_2 that minimizes S_r, we differentiate S_r with respect to each coefficient:

$$\frac{\partial S_r}{\partial a_0} = -2\sum (y_i - a_0 - a_1 x_i - a_2 x_i^2) \tag{5}$$

$$\frac{\partial S_r}{\partial a_1} = -2\sum x_i (y_i - a_0 - a_1 x_i - a_2 x_i^2) \tag{6}$$

$$\frac{\partial S_r}{\partial a_2} = -2\sum x_i^2 (y_i - a_0 - a_1 x_i - a_2 x_i^2) \tag{7}$$

By setting the differentiations, we obtain the following equations:

$$(n) a_0 + (\sum x_i) a_1 + (\sum x_i^2) a_2 = \sum y_i \tag{8}$$

$$(\sum x_i)a_0 + (\sum x_i^2)a_1 + (\sum x_i^3)\,a_2 = \sum x_i y_i \quad (9)$$

$$(\sum x_i^2)a_0 + (\sum x_i^3)a_1 + (\sum x_i^4)\,a_2 = \sum x_i^2 y_i \quad (10)$$

The optimal coefficients can be obtained by simultaneously solving these equations. Then, the final value is determined from f1 and f2 using linear interpolation as follows:

$$F = f_1 + \frac{(f_1 + f_2)\Delta x}{X} \quad (11)$$

4 EXPERIMENTAL RESULTS

Table 1 shows the SNR comparison of the bilinear interpolation method, the quadratic interpolation method and the least square quadratic regression method for the column data. It can be seen that the quadratic regression method provides noticeably improved results.

Table 1: The SNR(dB) of LUT column data.

	0 gray	32 gray	64 gray	96 gray	128 gray	160 gray	192 gray	224 gray	255 gray
A*	35.4	39.0	40.3	41.4	42.5	42.2	41.1	39.8	41.6
B*	36.2	41.6	43.7	43.0	43.4	43.9	42.2	39.8	35.3
C*	40.5	44.5	47.0	45.8	46.0	50.1	46.9	43.6	44.6

A*: Linear Interpolation (AVG: 40.4)
B*: Quadratic Interpolation (AVG: 41.0)
C*: Least Square Quadratic Regression (AVG: 45.4)

Table 2: Number of LUT coefficients.

Method for LUT Implementation	Number of Coefficients
Bilinear Interpolation	144
Quadratic Interpolation	108
Least Square Quadratic Regression	108

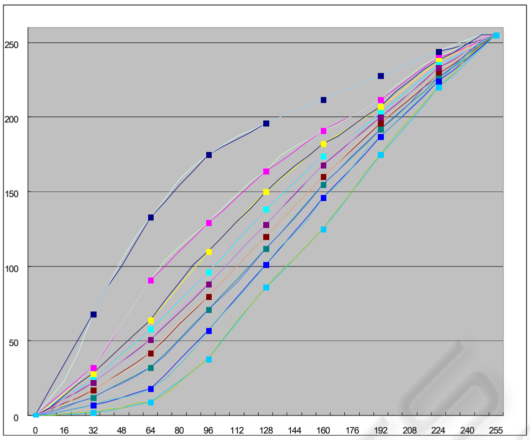

Figure 5: Curve fitting of the column data of LUT using bilinear interpolation.

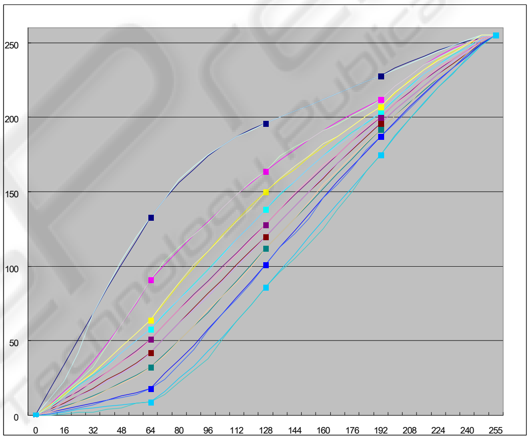

Figure 6: Curve fitting of the column data of LUT using quadratic interpolation.

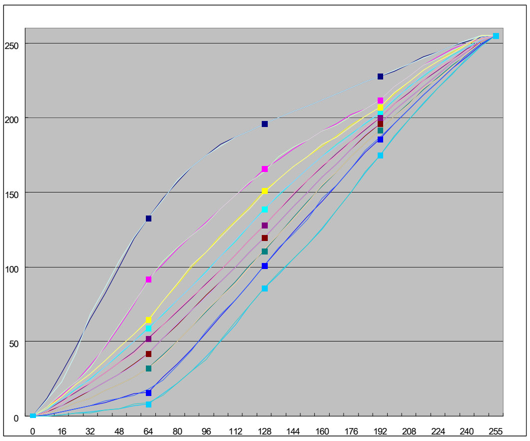

Figure 7: Curve fitting of the column data of LUT using least square quadratic regression.

In ASIC LUT implementation, the coefficients are saved in memory for computation efficiency. Table 2 shows the number of LUT coefficients for each method. It can be seen that the least square quadratic regression method provides more efficient memory usage in ASIC implementation. Figure 5-7 show the curve fitting of the column data for each method. It can be seen that the least square quadratic regression method generate curves that have smaller error than other methods.

After computing the column data, final overdriving values can be calculated by applying linear interpolation for the row data. The bilinear interpolation method, the quadratic interpolation method and the quadratic regression method used bilinear interpolation for the row data since the row data of LUT show linear characteristics (Figure 3).

In the conventional bilinear interpolation method, 64 samples (8 by 8) are selected from the entire LUT data (256 by 256). The sampling grids are equally distributed. In the proposed method, every 4-th sample is chosen for the column data and every 8-th sample is selected for the row data. Thus, a total of 32 samples are used in the proposed method.

Table 3 shows the SNR comparison for LUT implementation and Table 4 shows the maximum error comparison. As can be seen, the proposed method significantly outperforms the bilinear method which is widely used in the industry.

Table 3: SNR comparison.

Method of LUT Implementation	SNR(dB)
Bilinear Interpolation	38.0
Quadratic Interpolation + Linear Interpolation	36.7
Quasi-bi-quadratic Interpolation	40.2

Table 4: Maximum Error Comparison.

Method of LUT Implementation	Response Time Error	Visual Distortion Error
Bilinear Interpolation	5.47 %	3.51 %
Quadratic Interpolation + Linear Interpolation	5.86 %	2.34 %
Quasi-bi-quadratic Interpolation	3.51 %	1.56 %

5 CONCLUSIONS

In order to provide improved performance in the LCD overdrive scheme, we propose to use the quasi-bi-quadratic interpolation that is based on the least square error approximation. The proposed method outperforms the conventional bilinear interpolation method with reduced memory requirement.

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