Table Lookup-based Power Estimation for LCD Panels

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Abstract

We present a novel power estimation technique for LCD panels. Our method considers the power consumed by each pixel as well as the inter-pixel power effect of the neighboring pixels. We implemented our method based on the table lookup model and its accuracy is about 98% compared to the actual measurements.

1. Introduction

Low power is one of the most critical metrics for portable devices. In such devices, LCD panel is one of the major power consumers, hence its power reduction is significantly important. For this reason, several researches have been studied to reduce power consumption of LCD panels, recently [1]-[5]. To develop a power reduction technique, a power estimation technique should be developed *a priori* to assess the impact of the reduction techniques easily. Without the accurate estimation technique, an LCD panel with each reduction technique should be manufactured and only actual measurement can evaluate its effect, which is very expensive and time consuming. For this purpose, several power estimation techniques for LCD panels were proposed [6]. One of the most challenging issues in LCD panel power estimation is that its power consumption highly varies depending on the image patterns to be displayed.

Our analysis identified that there are two major power components for LCD panel power consumption. The first component is the charging / discharging of each pixel by the given input data voltage. The second component is the inter-pixel power consumption by parasitic effects among the neighboring pixels. Its impact becomes more significant with inversion scheme. We modeled each component as a table built from actual measurements of several sample images and the overall estimation accuracy reaches about 98% even for the complex image patterns.

The rest of this paper is organized as follows. We first describe the power estimator overview in section 2. Experimental results are given in section 3. Section 4 conclude in summary.

2. Power Estimation Overview

2.1. Overall Structure

Our power estimation method consists of two power estimators and power tables. The procedure for estimating the power consumption of complex image patterns is shown in Fig. 1. The pixel power estimator predicts the power consumed by each pixel which is determined by the input voltage corresponding to the given gray-scale data using pixel power table which is already known. The inter-pixel power estimator calculates the power consumption between adjacent pixels in a similar way to the pixel power estimator.

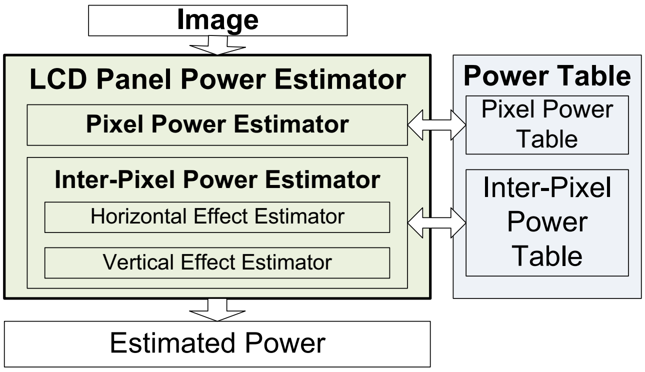

Fig.1. Overall structure of power estimator
– pixel power estimator and inter-pixel power estimator

The inter-pixel power estimation step is further divided in two parts. The first part is a horizontal inter-pixel power estimator that evaluates the power consumption due to the parasitic capacitor effect between two horizontally neighboring pixels. Similarly, the other part is a vertical inter-pixel power estimator which computes the power consumed by the parasitic capacitor effect between two vertically neighboring pixels. The voltage difference between two adjacent pixels is the critical parameter of inter-pixel power estimation. The total power consumption of an LCD panel is estimated by the sum of the results from both estimators. For each estimator, we adopt a table lookup model which well captures the non-linearity between the power and voltage variation as shown in Fig. 2. Power table built from actual measurement of some sample images. Details are explained later subsection.

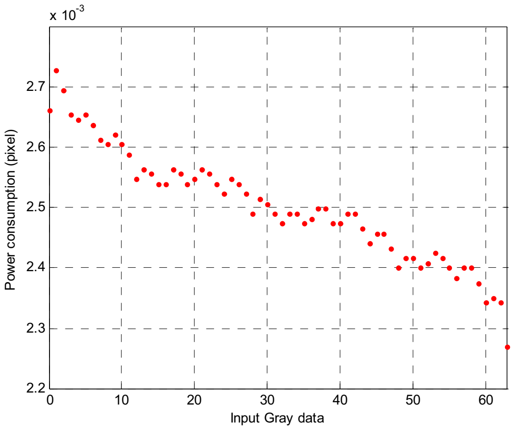

Fig. 2. Power consumption vs. Gray-scale data

2.2. Pixel Power Estimator

Each pixel has several parasitic capacitors. Pixel power consumption depends on charging / discharging these capacitors which is proportional to the input gray voltage determined by the input image. Hence, pixel power consumption is determined by the total capacitance and input voltage. The pixel power table is shown in Fig. 3. The power value of each row is easily obtained by the actual measurement of an LCD panel when it is displaying a solid image pattern not to include the power consumption due to the inter-pixel effect. The first column represents gray-scale data and the second column indicates the corresponding power consumption of a pixel when the pixel is driven by the corresponding voltage. Hence, the size (the number of rows) of the table is same to the size of gray-scale set.

For instance, each gray-scale pixel value of the image for the first row is zero and second row is one. Similarly, each gray-scale pixel value of the image for the last row is 63 when a 6-bit gray-scale set is considered.

Gray Level	*Power Consumption (uW)*
0	2.476
1	2.431
:	:
31	2.251
:	:
63	1.911

Fig. 3. Pixel power table

2.3. Inter-Pixel Power Estimator

Basically, LCD panel is a 2-dimensional array of pixels. Suppose that every pixel has same parasitic capacitance. The important factor of inter-pixel effect is voltage difference between the neighboring pixels. Inter-pixel power consumption due to the parasitic capacitors effect can be modeled similar to the pixel-power estimator. The inter-pixel power model is shown in Fig. 4. Unlike the pixel power table, the first column is replaced by the difference of gray-scale data between two neighboring pixels. Therefore, it also has the rows as many as the pixel power table. The second column indicates the corresponding power consumption of horizontal parasitic capacitors effect when the corresponding voltage is the difference of horizontal pixels. Similarly, the third column indicates the power consumption of vertical parasitic capacitor effect.

Gray-level Diff.	*Horizontal (uW)*	*Vertical (uW)*
0	0.0049	0.0040
1	0.0098	0.0081
:	:	:
31	0.1568	0.1294
:	:	:
63	0.3136	0.2589

Fig. 4. Inter-pixel power table

3. Experimental Results

We validate our method for an LCD panel named as LTN154X1 from SAMSUNG Electronics. Its resolution and diagonal size are 1280x800 and 15.4 inches, respectively. We compared our method with the method proposed in [6] which does not consider the inter-pixel parasitic effect. To compare our method, we prepare five image patterns. Pattern (a) and (b) are horizontally or vertically striped pattern which consist of RGB color. Pattern (c), (d), and (e) are much complicated images that consist of unknown gray-value. Fig. 5 shows these patterns.

As Table 1 shows our method outperforms the method in [6] in terms of accuracy. While average estimation accuracy of method in [6] is 85.71%, accuracy of out method is 98.06%. This is much higher than method in [6]. Our method considers the power consumption of each pixel as well as considers the power consumption due to the inter-pixel effects. Therefore, our method reaches estimation accuracy above 98%.

4. Summary

In this paper, we propose a novel power estimation technique for the LCD panels. Our method considers the power consumption due to input gray value as well as considers the power consumption due to the parasitic effect between the neighboring pixels. We modeled power table built from actual measurements of several sample images. And accuracy of our method is about 98% compared to actual measurements.

5. Acknowledgement

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6. References

1. S. T. Kim, B. D. Choi, and O. K. Kwon, "A Novel Method of Charge-recycling TFT-LCD Source Driver for Low-power consumption", *Proc. International Display Workshops*, pp. 155-158. (1997).
2. A. Erhart and D. McCartney, "Charge Conservation Implementation in an Ultra Low-power AMLCD Column Driver utilizing Pixel Inversion", *SID 97 digest*, pp. 23-26. (1997).
3. J. Kim, D. Jeong, and G. Kim, "A Multi-level Multi-phase Charge-Recycling Method for Low-power AMLCD Column Driver", *IEEE Journals. Solid-State Circuits*, vol. 35, no.1, pp.74-84. (Jan, 2000.)
4. Shao-Sheng Yang, Pao-Lin Guo, Tsin-Yuan Chang, and Jin-Hua Hong, "A Multi-phase Charge-Sharing Technique without External Capacitor for Low-Power TFT-LCD Column Drivers", *Proc. International Symposium on Circuits and Systems,* vol. 5. pp. 365-368. (May, 2003)
5. Dan Li, Tingcun Wei and Wei Wu, "A Novel Charge Recycler for TFT-LCD Source Driver IC", *Great Lakes Symposium on VLSI'07*, pp. 156-159. (2007).
6. I. Hwang, S. Kang, S. Moh, W. Park, and W. Kim, "Accurate Power Estimation of LCD Panels for Notebook PC Applications", *SID 07 digest*. 38, 264-267. (2007).

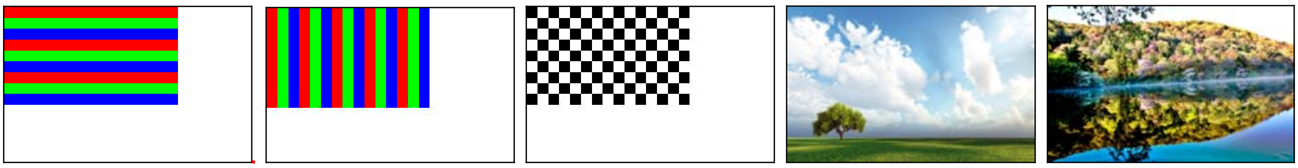
(a) horizon-RGB **(b) vertical-RGB** **(c) 1-dot** **(d) test1** **(e) test2**

Fig. 5. Test Image

Table 1. Power estimation accuracy comparison

Patterns	Measurements	Method in [6]	Our method	Accuracy of Method in [6] (%)	Accuracy of our method (%)
(a)horizon-RGB	7940.309	6475.72	8247.73	81.56	96.27
(b)vertical-RGB	7231.001	6476.51	7504.88	89.57	96.35
(c)1-dot	8491.993	6324.66	8569.25	74.48	99.10
(d)test1	7171.782	6461.62	7174.58	91.10	99.96
(e)test2	7132.486	6550.05	7032.86	91.83	98.60
Accuracy				85.71	98.06