Delta-Color Adjustment (DCA) for Spatial Modulated Color Backlight Algorithm on High Dynamic Range LCD TVs

Guo-Zhen Wang, Fang-Cheng Lin, and Yi-Pai Huang

***Abstract*—A high-dynamic-range liquid crystal display (HDR-LCD) which studies as a dual-panel display can much enhance the contrast ratio of image and reduce the power consumption upon the locally controlled dynamic backlight. A simple modulated algorithm, Delta-Color Adjustment (DCA) method, was proposed to determine the RGB-LEDs backlight modulation for high image quality. By implementing the DCA method on a 37" HDR-LCD TV with 8×8 backlight zones, the contrast ratio of a high contrast image can reach ∼ 40000:1 with clear image detail and 40% power reduction. Furthermore, by controlling the R, G, and B LEDs individually, the color gamut can be enlarged to 125% NTSC.**

***Index Terms*—Color backlight, contrast ratio (CR), dual-panel, high dynamic range (HDR), power consumption.**

I. INTRODUCTION

IMAGE quality and power consumption have become major issues for commercial monitors/TVs. However, a drawback of conventional LCDs is low contrast ratio (about 1000:1) as a result of the light leakage of liquid crystals and non-perfect polarizers. After dynamic-backlight-controlled technologies were proposed, the image dynamic range of LCDs could be improved [1]–[4]. Therefore, a suitable backlight algorithm has become an important part in high dynamic range (HDR) systems. Three different methods, Square Root, MAX, and IMF (Inverse of a Mapping Function) [5], were reported for backlight signal determination. The "Square Root" method was to calculate the average gray level of all sub-pixel values in each backlight region first, and then take its square root after normalizing it. However, square root method could not get enough brightness in high gray level [1]. The "MAX" method was to take the maximum gray level of all sub-pixel values in each backlight region. The max method could preserve a lot of details, but the light leakage of liquid crystals in low gray level could not be reduced effectively, thus the contrast ratio was not obviously increased. For above reasons, the "IMF" method was proposed to optimize above drawbacks [6]. IMF method cumulated the histogram for each frame to obtain the cumulative function. Finally, inverse the cumulative function of the image with the oblique line ($y = x$) [6], and used the new curve to map the new backlight signals. IMF is similar to a dynamic gamma for backlight modulation, thus can optimize the backlight signal according to each input image.

However, the square root, max, and IMF methods were considered the intensity control only, and without calculating red, green and blue inputs independently. Therefore, the power saving and enhancement of color gamut were limited. Moreover, if those methods (square root, max, and IMF) were applied on three inputs of color channel individually, the calculation process complexity must be increased with a factor of 3 (Fig. 1).

Consequently, we propose an efficient method for the color backlight modulation, the Delta-Color Adjustment (DCA) method, which is simpler than calculating the inputs of RGB three-color channels individually. As shown in Fig. 1, the DCA method can simply optimize the original intensity backlight signals according to the each input image, thus can not only use less calculation process but also enhance contrast ratio, enlarge NTSC gamut, and lower power consumption.

II. CONCETPT AND PROCESS OF DCA METHOD

A. Concept of DCA Method

Several intensity controlled methods have been proposed to successfully enhance image quality [1]–[15].In this paper, we proposed an efficient color backlight control method, the Delta-Color Adjustment (DCA) method, to modulate three-dimension (R, G, and B) backlight signals to optimize the backlight image.

The DCA algorithm is shown in Fig. 2. The intensity BL is regarded as coarse backlight signals. Finally, final color backlight signals can be calculated by fine tuning the tree coarse inputs of color channel (R, G, and B). For coarse value, the backlight signals of each frame can be determined by various intensity controlled methods to be intensity BL, such as the square root, MAX, or IMF methods. Afterwards, the intensity BL is divided into three equal backlight signals ($\mathrm{BL(R)} = \mathrm{BL(G)} = \mathrm{BL(B)}$) for color channel. Next, the gray level values of color pixels (R, G, and B) in each backlight block (division) are averaged individually to be the reference values. Finally, the references were used to calculate three delta BL values ($\Delta\mathrm{BL_R}$, $\Delta\mathrm{BL_G}$, and $\Delta\mathrm{BL_B}$) for modifying three BL signals ($\mathrm{BL(R)}$, $\mathrm{BL(G)}$, and $\mathrm{BL(B)}$) individually. Therefore, the key

---

Manuscript received March 12, 2009; revised June 20, 2009. Current version published April 16, 2010. This work was supported in part by the National Science Council, Taiwan, for the Academic Project NSC96-2221-E-009-113-MY3.

G.-Z. Wang is with the Display Institute, National Chiao Tung University, Hsinchu, Taiwan, 30010 (e-mail: cutetaurus.di95g@nctu.edu.tw).

F.-C. Lin is with the National Chiao Tung University, Department of Photonics & Institute of Electro-Optical Engineering, Hsinchu 30010, Taiwan.(e-mail: fclin.eo93g@nctu.edu.tw).

Y.-P. Huang is with the Display Institute, National Chiao Tung University, Hsinchu 30010, Taiwan (e-mail: boundshuang@mail.nctu.edu.tw).

Color versions of one or more of the figures in this paper are available online at http://ieeexplore.ieee.org.

Digital Object Identifier 10.1109/JDT.2009.2037164

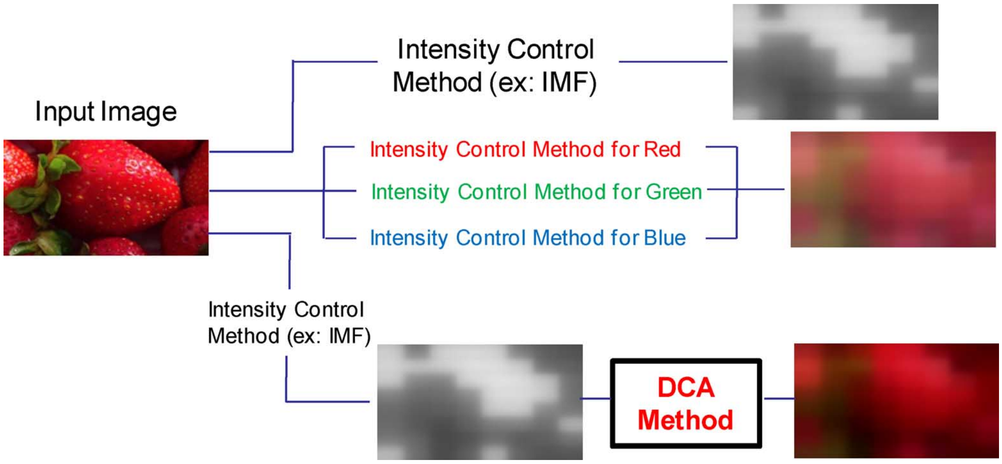


Fig. 1. Flowchart of different BL algorithms.

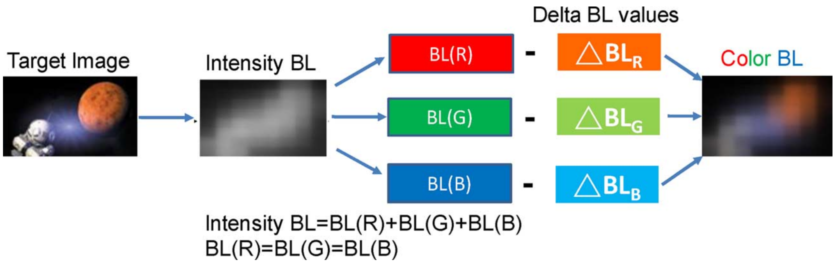


Fig. 2. Flowchart of the DCA algorithm.

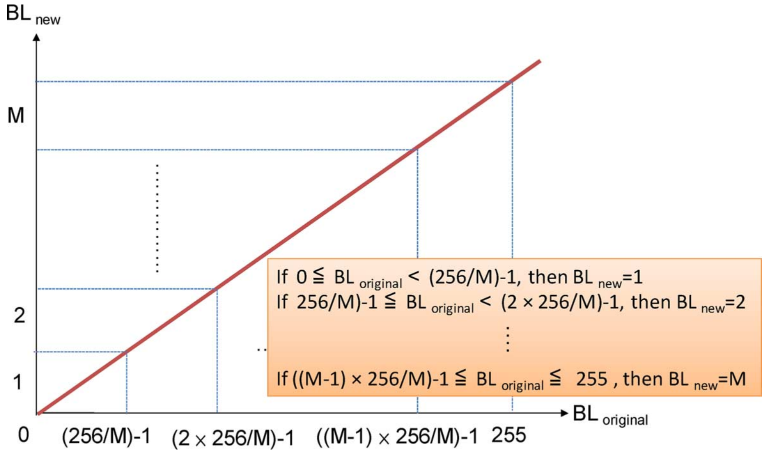
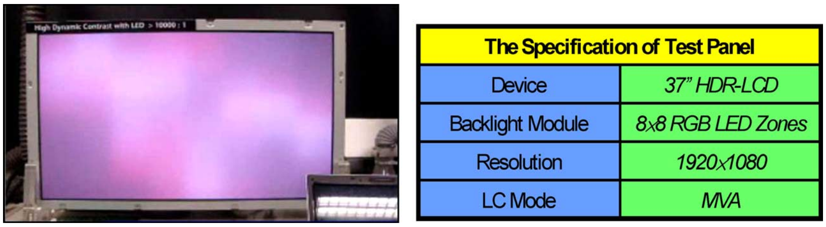


Fig. 3. Mapping curve of the backlight values transform.

point of the DCA method is how to determine the modified delta BL values ($\Delta \mathrm{BL}_{\mathrm{R}}$, $\Delta \mathrm{BL}_{\mathrm{G}}$, and $\Delta \mathrm{BL}_{\mathrm{B}}$). Besides, the operation of DCA method has low complexity. It is because that DCA only require average method and three delta BL values ($\Delta \mathrm{BL}_{\mathrm{R}}$, $\Delta \mathrm{BL}_{\mathrm{G}}$, and $\Delta \mathrm{BL}_{\mathrm{B}}$).

B. Delta-Value Determination

For modifying backlight signals, the BL gray-level (0~255) was divided into equal M (adjustment division) parts to map the new value ($1 \sim \mathrm{M}$) as shown in Fig. 3. Following, mapping the intensity BL of each backlight block to obtain the new mapping value ($\mathrm{MAP}_{\mathrm{intensity}}$). Next, the average gray level values of color pixels (R, G, and B) in each backlight block were calculated individually, and used the same mapping curve (Fig. 3) to map three reference values ($\mathrm{MAP}_{\mathrm{r,g,b}}$). Following, the three transient BL values ($\mathrm{T}_{\mathrm{r,g\ ,b}}$) were defined as shown in (1). Furthermore, an $\mathrm{N}_{\mathrm{threshold}}$ value was set as the threshold value for adjustment [see (2)]. While the three transient BL values ($\mathrm{T}_{\mathrm{r,g\ ,b}}$) are larger than $\mathrm{N}_{\mathrm{threshold}}$ value, the three input backlight signals of color channel (R, G, and B) will be dimmed, otherwise will maintain the same value as intensity BL ($\mathrm{MAP}_{\mathrm{intensiy}}$) due to the power issue. Finally, multiplying



The Specification of Test Panel	
Device	*37" HDR-LCD*
Backlight Module	*8x8 RGB LED Zones*
Resolution	*1920x1080*
LC Mode	*MVA*

Fig. 4. A 37 inch HDR-LCD panel with color controlled backlight.

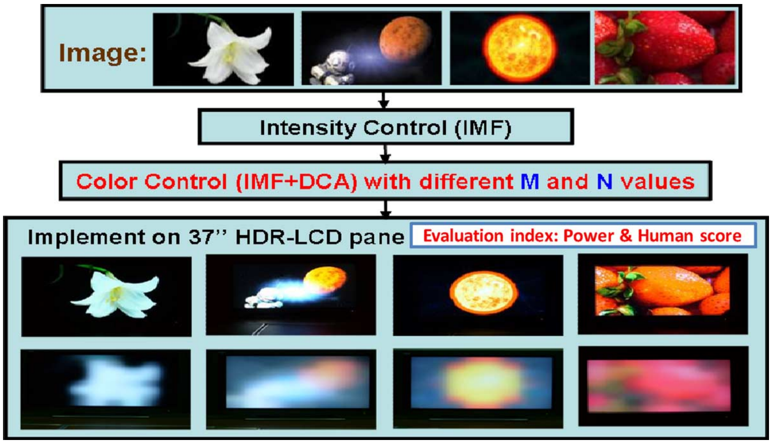


Fig. 5. Experimental flow of delta BL values.

$256/M$by three delta values ($\mathrm{D_{r,g,b}}$) individually to get three delta BL values ($\Delta\mathrm{BL_{R,G,B}}$), as shown in (3)

$$\mathrm{MAP_{intensiy}|MAP_{r,g,b}} = \mathrm{T_{r,g,b}} \tag{1}$$

If $\mathrm{T_{r,g,b}} > \mathrm{N_{threshold}} \rightarrow$

$$\mathrm{D_{r,g,b}} = \mathrm{T_{r,g,b}} - \mathrm{N_{threshold}},\ \text{else}\ \mathrm{D_{r,g,b}} = 0 \tag{2}$$

$$\Delta\mathrm{BL_{R,G,B}} = \mathrm{D_{r,g,b}} * 256/\mathrm{M}. \tag{3}$$

Different M (adjustment division) and N (adjustment threshold) values will influence image quality and power consumption in the DCA method. Therefore, a 37" HDR-LCD which was divided into 8×8 zones with 1920 × 1080 MVA-LC panel by using spatial modulated color backlight and LC compensation (Fig. 4), was set up to optimize the suitable M and N values.

C. Delta BL *Parameters* (M, N) *Optimization*

The critical factor of the DCA method was to determine suitable delta BL values ($\Delta\mathrm{BL_R}$, $\mathrm{MAP_G}$, and $\Delta\mathrm{BL_B}$), which affected by M (adjustment division) and N (adjust threshold). For optimizing the M and N values, the experimental flow is shown in Fig. 5. At first, four different images, *Lily, Robot, Sun*, and *Strawberry*, were chosen as experimental target images. Second, the inverse of a mapping function (IMF) method was chosen as the intensity controlled method (Because that IMF has optimized contrast ratio with low power consumption) [6]. Finally, power consumption and image distortion (Human score) were selected for evaluation indices on 37" HDR-LCD.

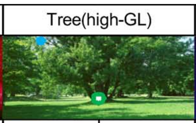
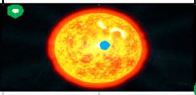
TABLE I
CHARACTERISTICS OF EACH OBSERVER.

Observer	**Age**	**Male/Female**
GW	25	Male
SC	30	Male
C	28	Male
LL	24	Male
RS	24	Female
RB	24	Male
ZS	26	Male

A conventional evaluation index for the image details of an HDR-LCD was distortion ratio which did not consider human vision. Therefore, human adjust score was proposed to evaluate the image details by psychophysics experiments. The image details were evaluated by seven different observers. They have normal color vision with ages range from 24 to 30 years. The data of observers are summarized in Table I.

The adjust range of human score was 0 to 10 (10 is the best).The experimental results of human score are shown in Fig. 6(a). Obviously, the larger N (higher threshold) would get less image distortion, but power consumption would be increased as shown in Fig. 6(b). As a result, image distortion and power consumption are the trade-off. To obtain the indistinguishable image distortion ($\mathrm{human\ score} = 10$) and the lowest power consumption, the optimizing values were decided as $M = 16$ and $N = 6$ which could get the optimized balance point with power consumption and image quality by using the DCA method.

TABLE II
THE LUMINANCE ($\mathrm{L_{max}}$ AND $\mathrm{L_{min}}$), CR, AND POWER CONSUMPTION OF DIFFERENT IMAGES BY USING THE CONVENTIONAL METHOD (FULL-ON) AND TWO DIFFERENT BACKLIGHT DETERMINATION METHODS (IMF AND IMF+DCA).

Target Image	Strawberry(colorful)		Tree(high-GL)		Campanline(colorful)		Mountain(mid-GL)	
○ Min:minimum luminance ● Max:maxmium luminance								
Backlight Algorithm	Power	CR	Power	CR	Power	CR	Power	CR
Full on	190	417	190	129	190	308	190	743
IMF	138	847	186	139	80	312	147	2027
IMF+DCA(M=16,N=6)	94	829	176	146	77	341	135	2138
Target Image	Night View(mid-GL)		Robot(dark)		Sun(particular)		Lily(high CR)	
○ Min:minimum luminance ● Max:maxmium luminance								
Backlight Algorithm	Power	CR	Power	CR	Power	CR	Power	CR
Full on	190	216	190	1465	190	1394	190	1352
IMF	142	317	138	4038	170	1800	92	21230
IMF+DCA(M=16,N=6)	128	322	110	4636	116	2704	79	40870

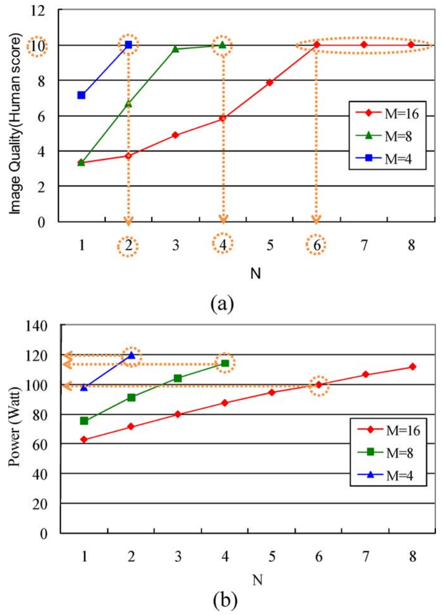


Fig. 6. (a) Average image distortion score and (b) power consumption of IMF+DCA ($M = 16, 8,$ and 4).

III. EXPERIMENT

A. Hardware and the Test Images

Due to the human vision has high dynamic range, the main purpose of the HDR system was to produce a high contrast ratio (CR) image to match the human vision range [16]. In our experiment, the CR was measured by using a luminance analyzer, CA-210 [17], with a measuring area of 27 mm in diameter (covering about 12,834 pixels).

Eight target images were implemented on a 37" HDR-LCD TV with 8 × 8 backlight zones. The positions of maximum luminance ($\mathrm{L_{max}}$) and minimum luminance ($\mathrm{L_{min}}$) are respectively marked with a blue solid dot and a green hollow dot, as shown in Table II. The area within the red rectangle parts are magnified for image detail comparison, as shown in Fig. 7.

B. Results and Discussions

The experimental results of the eight target images are listed and shown in Table II. The high detail images are partly magnified and shown in Fig. 7. The image details in the high brightness region were almost preserved by using IMF and IMF+DCA ($M = 16$, $N = 6$). The power consumption and contrast ratio (CR) by using the full-on, intensity control (IMF) and color control (IMF+DCA) backlights were compared and shown in Fig. 8. The CR of the IMF+DCA method was much higher than that of the IMF method and full on backlight, especially in the high CR image, *Lily (DCA+IMF:* $\mathrm{CR} = 40,870$*, IMF:* $\mathrm{CR} = 21,230$*, Full on:* $\mathrm{CR} = 1,325$*)*. Besides, the power consumption of all the target images was also much reduced by using the IMF+DCA method. Especially the colorful image, *Strawberry*, IMF+DCA method also maintained CR but much saved power to $\sim 50\%$ compared to that of full-on Backlight. Besides, due to the less of light leakage as show in Fig. 9, the DCA method could enhance color gamut from 107.7% to 125.4% NTSC, as the red solid line shown in Fig. 10.

DCA method can optimize power consumption due to considering three inputs of color channel individually. Furthermore, CR can be enhanced by dimming delta BL values ($\Delta\mathrm{BL_{R,G,B}}$) in dark regions. Therefore, the DCA method is a good option for color backlight determination in optimizing image quality and reducing power consumption for HDR-LCDs.

IV. CONCLUSIONS

A color-backlight determination algorithm for high dynamic range displays named "Delta-Color Adjustment (DCA)" method was proposed and successfully implemented on a 37'' HDR-LCD TV. The concept of the DCA method is based on an intensity controlled method than update suitable "delta" values to get modified color-backlight signals.

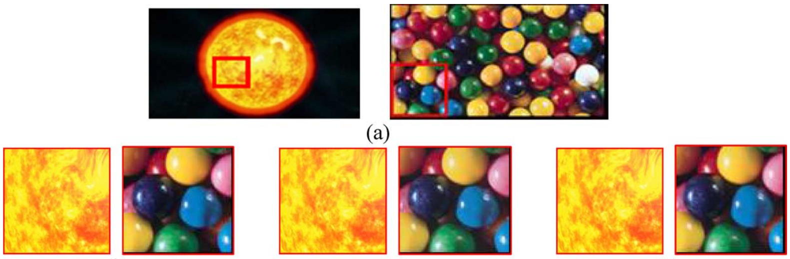
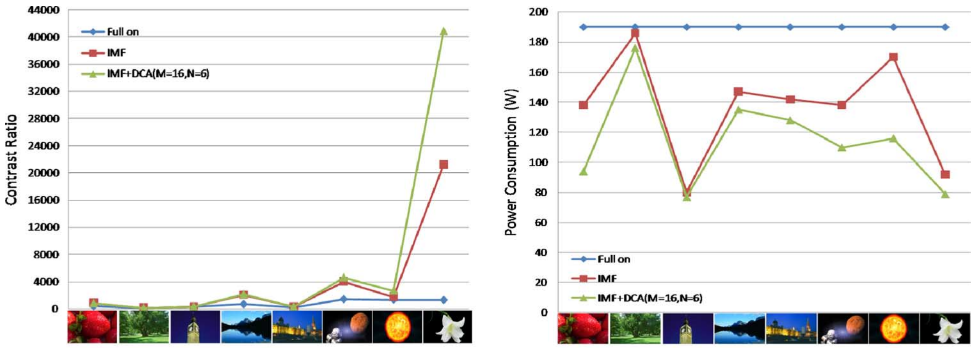

(a)
(b) (c) (d)

Fig. 7. (a)Two target images within the red rectangle, (b) the magnified section in target images, (c) and (d) are produced by using IMF and IMF+DCA ($\mathrm{M} = 16$, $\mathrm{N} = 6$) methods, respectively.



(a) (b)

Fig. 8. Image characteristics of different images with different methods: (a) CR and (b) power.

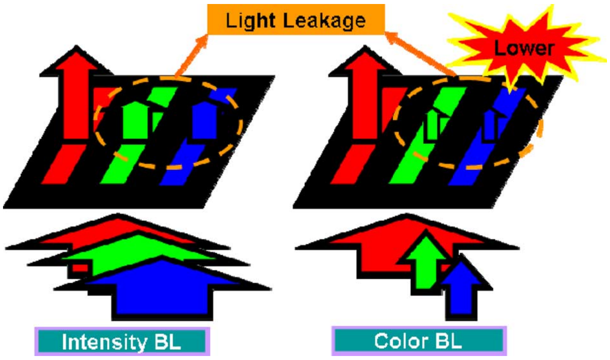


Fig. 9. Light leakage of intensity backlight and color backlight.

From the experimental results, two major parameters, M (adjustment division) and N (adjust threshold), of the DCA method were selected as $M = 16$ and $N = 6$ respectively by optimizing image quality and power consumption. The DCA method can not only reduce the power consumption ($\sim 50\%$ to the full-on) but also achieve high contrast ratio ($\sim 40{,}000 : 1$ of the test image—*Lily*), which can still preserve clear image details. Furthermore, by controlling the R, G, and B LEDs individually, the color gamut can be enlarged to 125% NTSC.

In summary, the DCA method can yield high image quality with simple delta value for hardware implementation. Therefore, the DCA method could be an option for color-backlight HDR-LCD applications to optimize image quality, power consumption, and hardware complexity.

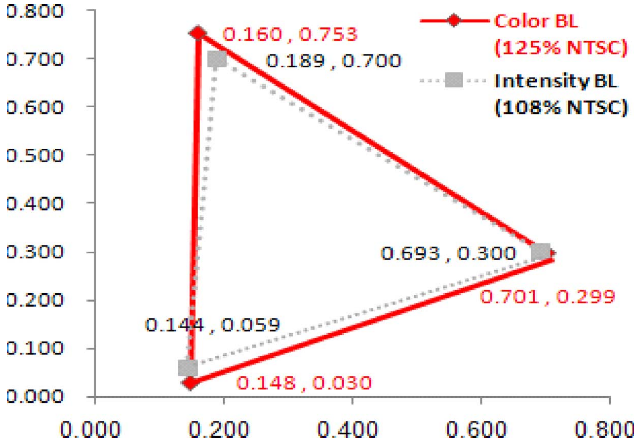


Fig. 10. Color gamut of an HDR-LCD TV.

ACKNOWLEDGMENT

The authors would like to thank J. Lyu and S.-C. Yeh of AU Optronics Corporation, Hsinchu, Taiwan, for hardware support.

REFERENCES

[1] H. Seetzen, W. Heidrich, W. Stuerzlinger, G. Ward, L. Whitehead, M. Trentacoste, A. Ghosh, and A. Vorozcovs, "High dynamic range display systems," *ACM Trans. Graphics*, vol. 23, no. 3, pp. 760–768, 2004.

[2] M. D. Tisdall, G. Damberg, P. Wighton, N. Nguyen, Y. Tan, M. S. Atkins, H. Li, and H. Seetzen, "Comparing signal detection between novel high-luminance HDR and standard medical LCD displays," *J. Display Technol.*, vol. 4, no. 4, p. 398, Dec. 2008.

[3] E. Y. Oh, S. H. Baik, M. H. Sohn, K. D. Kim, H. J. Hong, J. Y. Bang, K. J. Kwon, M. H. Kim, H. Jang, J. K. Yoon, and I. J. Chung, "IPS-mode dynamic LCD-TV realization with low black luminance and high contrast by adaptive dynamic image control technology," *J Soc Inf Display*, vol. 13, pp. 215–219, 2005.

[4] C. H. Chen and H. P. D. Shieh, "Effects of backlight profiles on perceived image quality for high dynamic range LCDs," *J. Display Technol.*, vol. 4, no. 2, p. 153, 2008.

[5] F. C. Lin, C. Y. Liao, L. Y. Liao, Y. P. Huang, and H. P. D. Shieh, "Inverse of mapping function method for image quality enhancement of high dynamic range LCD TVs," in *SID Symp. Dig. Tech Papers*, 2007, vol. 38, pp. 1343–1346.

[6] F. C. Lin, Y. P. Huang, L. Y. Liao, C. Y. Liao, H.-P. D. Shieh, T. M. Wang, and S. C. Yeh, "Dynamic backlight gamma on high dynamic range LCDs," *J. Display Technol.*, vol. 4, no. 2, p. 139, Jun. 2008.

[7] M. Trentacoste, W. Heidrich, L. Whitehead, H. Seetzen, and G. Ward, "Photometric image processing for high dynamic range displays," *J. Visual Commun. Image Rep.*, vol. 18, pp. 439–451, 2007.

[8] J. Kuang, G. M. Johnsona, and M. D. Fairchild, "A refined image appearance model for HDR image rendering," *J. Visual Commun. Image Rep.*, vol. 18, pp. 406–414, 2007.

[9] M. Trentacoste, W. Heidrich, L. Whitehead, H. Seetzen, and G. Ward, "Photometric image processing for high dynamic range displays," *J. Visual Commun. Image Rep.*, vol. 18, pp. 439–451, 2007.

[10] M. Trentacoste, "Photometric image processing for HDR displays," Masters thesis, Univ. British Columbia, Vancouver, Canada, 2006.

[11] H. Seetzen and L. A. Whitehead, "A high dynamic range display using low and high resolution modulators," in *SID Symp. Dig. Tech. Papers*, 2003, pp. 1450–1453.

[12] K. D. Kim, S. H. Kuwahara, N. Takeo, and S. Mikoshiba, "Adaptive dimming technique with optically isolated lamp groups," in *SID Symp. Dig. Tech Papers*, 2005, pp. 992–995.

[13] J. Kuang, G. M. Johnsona, and M. D. Fairchild, "A refined image appearance model for HDR image rendering," *J. Visual Commun. Image Rep.*, vol. 18, pp. 406–414, 2007.

[14] H. G. Hulze and P. d. Greef, "Driving an adaptive local dimming backlight for LCD-TV systems," in *SID Symp. Dig. Tech Papers*, 2008, pp. 772–775.

[15] C. F. Hsu, C. C. Lai, and J. S. Li, "Backlight power reduction and image contrast enhancement using adaptive dimming for global backlight applications," in *SID Symp. Dig. Tech. Papers*, 2008, pp. 776–782.

[16] *High-Dynamic-Range (HDR) Vision*, B. Hoefflinger, Ed. New York: Springer, 2007, pp. 1–4.

[17] Konica Minolta Sensing, Inc., "Measurement Instruments CA-210," 2008.

Guo-Zhen Wang received the M.S. degrees in Display Institute from National Chiao Tung Univerity (NCTU), Hsinchu, Taiwan, in 2008, and is currently working toward the Ph.D. degree at the Institute of Electronics Engineering, (NCTU.

His current research is to develop 3D interaction systems, especially in signal processing and computer architecture technologies.

Fang-Cheng Lin received the M.S. degree from Department of Physics, National Cheng Kung University, Tainan, Taiwan, in 2002, and is currently working toward the Ph.D. degree from the Institute of Electro-Optical Engineering, National Chiao Tung University, Hsinchu, Taiwan.

His current research is to develop high image-quality with low power consumption LCDs, especially in high-dynamic-range and field-sequential-color technologies.

Yi-Pai Huang received the B.S. degree from National Cheng-Kung University in 1999, and the Ph.D. degree (with merit) from the Institute of Electronic-Optical Engineering, National Chiao Tung University (NCTU), Hsinchu, Taiwan.

He is currently an assistant professor in the Department of Photonics & Display Institute, National Chiao Tung University, Hsinchu, Taiwan. He was a project leader in the technology center of AU Optronics (AUO) Corporation from 2004 to 2006. He had joined the group of Photonics and Communications Laboratory, the School of Optics/CREOL, University of Central Florida (UCF, Orlando, from 2001 to 2002. His current research interests are Eco-display systems (High dynamic range LCD and Field sequential LCD), display human vision evaluation, 3-D displays, and display optics. He has published 12 journal papers, 40 international conference papers, and has 20 U.S. patents to his credit.

Dr. Huang was awarded the Society of Information Display (SID) SID2001 Best Paper Award, SID2004 Distinguished Paper Award. He is also the Secretary General of SID-Taipei chapter.