Characterization of crosstalk in high-resolution active-matrix liquid crystal displays for medical imaging

Aldo Badano and Jerzy Kanicki

Dept. of Electrical Engineering and Computer Science, University of Michigan, Ann Arbor, MI.

ABSTRACT

In active-matrix liquid crystal displays with large pixel array and large number of graylevels, the luminance of a pixel depends on the luminance of the rest of the image. This artifact known as crosstalk is caused by parasitic phenomena in the active-matrix array. When interpreting high information content medical images with subtle features and structured background, crosstalk can affect image fidelity and diagnostic performance. Conventional methods rely on the measurement of the luminance change of small square targets located across the screen when changing the background intensity. We present a method that describes both the magnitude and the spatial extent of the crosstalk artifact. The method is based on the formulation of a response function that corresponds to the differential contribution of a vertical or horizontal line to the luminance of a small centered target. The response function is defined for a given screen position, along the horizontal or vertical display axis. Our measurements show that subtle differences between vertical and horizontal crosstalk can be detected with the proposed method, and that most of the influence is confined to a 40-pixel region about the target. The results obtained with the proposed characterization method allow for the modeling of crosstalk effects to determine its impact on a variety of visual tasks.

Keyword List: small-spot contrast, electronic crosstalk, medical display, active-matrix liquid crystal display.

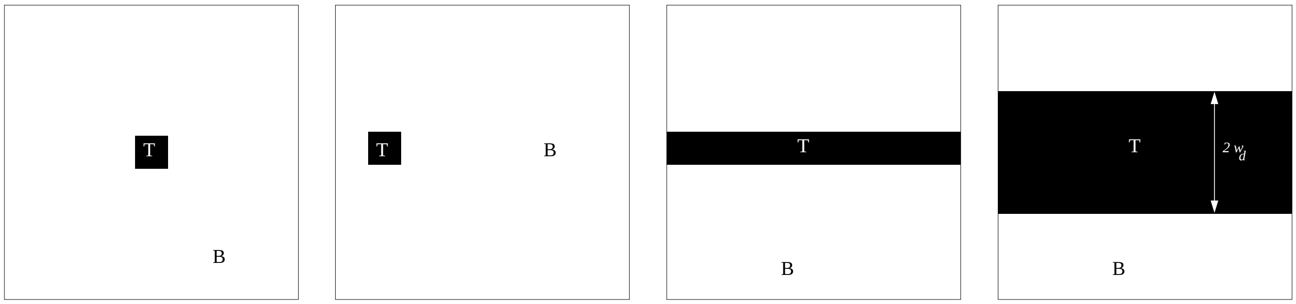
1. INTRODUCTION

Contrast measurements are an essential part of the assessment of display image quality. The contrast performance is typically determined by measuring the maximum and minimum luminance generated by the display using specific test patterns for a given experimental condition that should specify ambient illumination levels.[1] Both maximum and minimum luminance levels are defined before the measurement by the initial display calibration procedure. Although widely used particularly in active-matrix liquid crystal display (AM-LCD) specifications, the full-field contrast ratio of display devices determined with uniform bright and dark fields does not provide a complete characterization of the contrast response. All display contrast metrics are a function of the target size and, in AM-LCDs, are affected by electronic crosstalk. Electronic crosstalk is of particular importance in high-resolution flat-panel displays with a large number of graylevels.[2]

The undesired scene-dependent artifact is associated with an unwanted modification of the voltage effectively applied to the liquid crystal cell. The changes in pixel voltage translate into changes in light transmission through the liquid crystal, affecting the desired pixel luminance. Sources of crosstalk include incomplete pixel charging, leakage and photo-generated currents in the thin-film transistor, and parasitic capacitive coupling. Display crosstalk is more important for large size panels having higher resolution and grayscale. Several authors have studied the crosstalk artifact in large active-matrix arrays and have proposed modified driving techniques that compensate the signal distortion.[3–5] Others have focused their work on the study of the pixel voltage changes and its effect on transmission-voltage characteristics of the liquid crystal cell.[6] Although having different origins, crosstalk artifacts have been also studied for passive matrix organic polymer light-emitting displays.[7]

In the Flat Panel Display Measurements Standard,[1] methods to quantify display crosstalk are included in the grayscale artifacts Section, along with other related phenomena such as streaking, ghosting and trailing. Crosstalk is defined as "unwanted coupling between adjacent or nearby circuits that causes signal properties of one element to be injected into other elements". The standard suggests a classification into short- and long-range crosstalk effects. The complete characterization of electronic crosstalk in flat-panel displays with high quality for medical imaging applications requires the measurement of the small-spot luminance of a target in backgrounds of different intensity. In previous work, we have studied the degradation in contrast associated with veiling glare in a cathode-ray tube (CRT). Measurements of the small-spot contrast were used to determine a one-dimensional rotationally symmetric response function that characterizes veiling glare in CRTs.[8,9] The electronic crosstalk artifact is similar to veiling

Flat Panel Display Technology and Display Metrology II, Edward F. Kelley, Tolis Voutsas, Editors, Proceedings of SPIE Vol. 4295 (2001) © 2001 SPIE · 0277-786X/01/$15.00



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

Figure 1. Test patterns for crosstalk measurements. (a) and (b) represent patterns used in Ref. 9 with uniform background and with horizontal bar. The target (T) and background (B) were assigned 6 luminance levels from minimum to maximum. (c) and (d) are examples of the new test patterns used in this work, where the bar at a minimum luminance (T) increases its width ($2w_d$) sequentially. The background B is kept at maximum luminance.

glare in CRTs since both cause contrast reduction. However, crosstalk in AM-LCD presents a substantial difference with respect to veiling glare: the effect of crosstalk is not rotationally symmetric due to the matrix arrangement of the display circuitry. The effect is not shift-invariant since leakage and parasitic capacitance are not uniform across the display pixel matrix. Furthermore, the crosstalk artifact cannot be treated as linear with respect to the background intensity. In this paper, we propose to evaluate the electronic crosstalk artifact by studying the change in luminance of a centered dark bar target as its width increases, while the background remains at maximum luminance. This approach allows end-users to evaluate the magnitude of the crosstalk effect in AM-LCD monitors without having access to the device circuits and drivers.

2. METHODS

In a previous work, we reported measurements of display crosstalk made on a 1024×768 color AM-LCD using patterns having a small square target of about 1 cm surrounded by a uniform luminance field (see Figure 1a and 1b).[9] We found that the maximum change in target luminance associated with a change in background luminance was 1% corresponding to a centered white target in a uniform field at an intermediate graylevel. However, the measured data provided no information regarding the spatial extent of the crosstalk artifact. In this work, we introduce a response function that describes the magnitude and spatial profile of the one-dimensional contribution to the target luminance caused by crosstalk.

The derivation of the response function C is similar to the analytical model of veiling glare described in Ref. 10. Let us define the luminance at the center of the bar target when the bar width ($2w_d$) is equal to the screen width, as L_0. In an ideal display,* the luminance of the bar remains constant and equal to L_0 independently of w_d. In a real device, the luminance in the bar changes due to crosstalk from bright regions outside the target. Since the target luminance corresponds to the display minimum luminance, we expect an increase in luminance for both normally-white and normally-black displays. As a first approximation, we assume a linear relationship between L_c and the background luminance L_0. We can express the gain in luminance due to crosstalk as follows,

$$L_c = L_d + AL_0 \int_{w_d}^{w_{max}} C(w)dw \ , \tag{1}$$

where L_d is the measured minimum target luminance (when the bar covers the entire display screen), w_d is the bar half-width, and w_{max} is the screen half-width (see Figure 1d). The factor A is assumed to be equal to two, although the magnitude of the crosstalk in the center of the screen may not be symmetric. The function $C(w)$ has units of mm^{-1}. In the absence of electronic crosstalk, $C(w) = 0$ and therefore the luminance at the center of the bar target is

*For this work, an ideal display is defined as a display having no electronic crosstalk and no other artifact that would alter the desired defined as pixel luminance.

constant and equal to L_0. The analogy with the two-dimensional point-spread function defined in Ref. 10 comes from assuming that the crosstalk is well characterized by a one-dimensional function that depends on the bar half-width, w_d. As in our previous work, we consider edge effects negligible, although we have not investigated crosstalk in pixel locations at the periphery of the active-matrix array.

The response function for crosstalk $C(w)$ represents the differential contribution of a bright line in either horizontal or vertical direction to the luminance at the center of the screen. We measured C indirectly, by performing a discrete summation on the experimental data for bars of different width. From Equation 1, we can associate two measurements with different bar width, $L_1(w_1)$ and $L_2(w_2)$ to calculate C_{12}, the discrete crosstalk response for a line at $(w_1+w_2)/2$. Since $C(w)$ is slowly varying, we use this expression to numerically estimate $C(w)$ from a full set of measurements of L_i (for i varying from 0 to w_{max}):

$$L_1 - L_2 = AL_0\left(\int_{w_1}^{w_{max}} C(w)dw - \int_{w_2}^{w_{max}} C(w)dw\right) \text{ , and } L_1 - L_2 \sim AL_0 C_{12}(w_2 - w_1) \ . \qquad (2)$$

Under the assumption that C is constant within a small change in bar width (i.e., $w_1 \sim w_2$), we can compute the crosstalk response function as follows,

$$C_{12} \sim \frac{L_1 - L_2}{AL_0(w_2 - w_1)} \ . \qquad (3)$$

We carried out small-spot luminance measurements described in this paper using a collimated luminance probe and a high-gain detector.[10] The probe allows for the measurements of very low luminance levels from spots as small as 6 mm in diameter, without any significant contamination from a very bright surrounding. Although the function C may differ when measured at different screen locations, all data shown in this paper correspond to measurements of the crosstalk response at the center of the display screen. Measurements were performed in dimly lit rooms using a public domain software (DisplayTools, Version 1.2, public domain software, Radiology Research, Henry Ford Health System, Detroit, MI) to sequentially generate the bar test patterns.[11] We measured the response function $C(w)$ for two workstation quality AM-LCDs: LCD1 (1600×1024) and LCD2 (1280×1024). We adjusted the brightness and contrast controls for both monitors for optimum viewing of black characters on white background at low ambient illumination levels.

3. RESULTS

We measured the luminance in the center of the target using the test patterns shown in Figures 1c and 1d. In Figure 2, we present the ratio of the bright field luminance (L_0) to the target luminance (L_d) for the monitor LCD2.

The error bars are based on the propagation of uncertainty of the ratio using the standard deviation of 10 consecutive luminance measurements for the dark target and bright background. After a half-width of 3 mm, the contrast ratio converges to about 130 for both vertical and horizontal bars. Figure 3 shows the response functions in the horizontal and vertical directions for LCD1 and LCD2, with the same luminance data used in Figure 2 computed using Equation 3. In the case of LCD1, the magnitude of the crosstalk is low at distances larger than 10 mm approaching levels in the order of 10^{-5}-10^{-6}. At 10 mm, the crosstalk effect is in the order of 10^{-5}. We note a difference in the tails of the horizontal and vertical response functions. The horizontal crosstalk presents a peak at about 6 mm, and decreases to 10^{-6} at about 15 mm, while the vertical response decreases monotonically until 5×10^{-6}. This difference in final values of $C(w)$ could be attributed to the 16:10 aspect ratio of the monitor LCD1. For this monitor, the horizontal crosstalk is 5 times larger than the vertical crosstalk at large w_d.

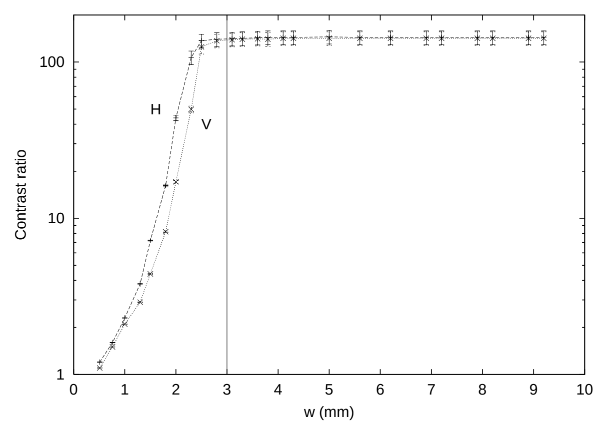
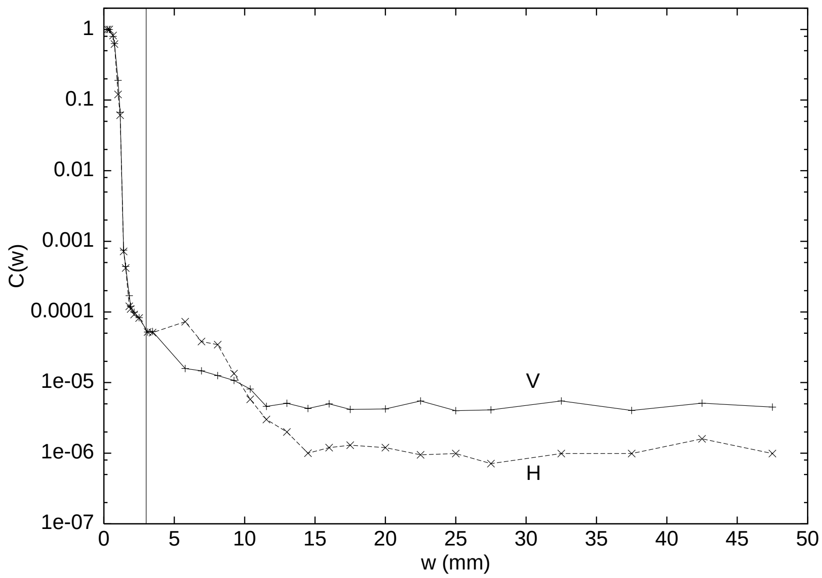
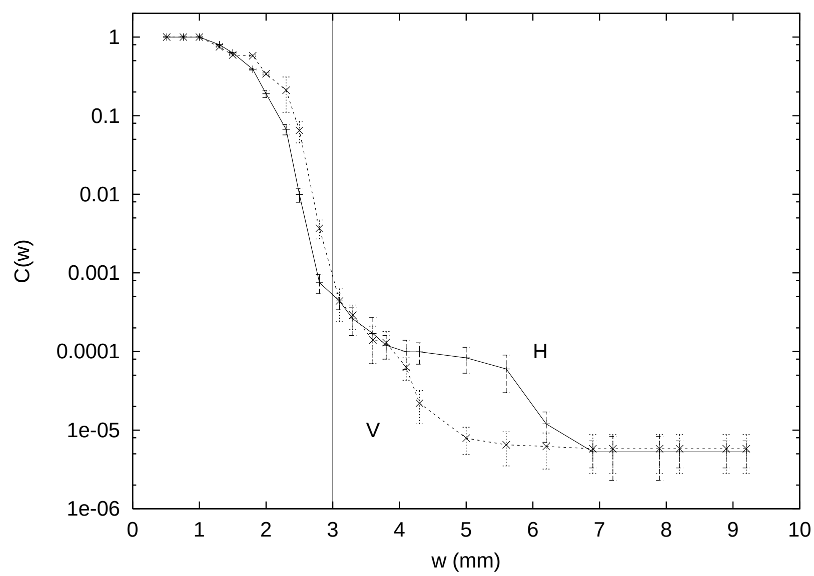


Figure 2. Contrast ratio for targets of increasing width for a horizontal (H) and a vertical (V) bar.



(a)



(b)

Figure 3. Crosstalk response functions $C(w)$ for LCD1 (a) and LCD2 (b) for a horizontal bar (H) and a vertical bar (V). The line at 3 mm indicates the minimum bar width that the method can measure due primarily to the field of view of the collimated luminance probe.[10] The error bars in plot (b) were computed using the standard deviation of 10 consecutive luminance measurements of the dark (L_1 and L_2, see Eq. 3) and bright fields.

For LCD2, both horizontal and vertical $C(w)$ converge to about 5×10^{-6}. In this case, we observe the same pattern noted for LCD1 for half-width w_d between the limiting minimum target size that can be measured (3 mm), and 7 mm, with the horizontal response having more strength than the vertical crosstalk. Data for $w < 3$ mm should not be interpreted as crosstalk since the signal comes from a target that is smaller than the effective field of view of the probe. According to Equation 1, we can estimate the luminance gain in the centered dark bar using the response functions $C(w)$ for any given test pattern consisting of a dark target and a bright surrounding field. For instance, for a 1 cm bar in a screen with a width of 31 cm, the relative luminance gain is given by

$$\frac{L_c}{L_0} = 2\int_{5\ mm}^{150\ mm} C(w)dw \sim 2(150-5)C' \ , \tag{4}$$

where C' is the asymptotic limit of $C(w)$ for $w_d > 10\ mm$. For LCD1, L_c/L_0 is about 0.0015 for a vertical bar and 0.0006 for a horizontal bar. For LCD2, both vertical and horizontal bars will be affected equally with a gain of about 0.0015.

If we consider that the gain due to horizontal and vertical crosstalk are independent and can be added to obtain the gain in luminance for a small square target,† we find that the relative increase in luminance is in the order of 0.42 % for LCD1, and 0.60 % for LCD2 for a dark target in a background at maximum luminance. Although the AM-LCD display used in our previous work was not included in this study, we found that the analysis of the crosstalk effect using the response function $C(w)$ reflects similar magnitudes of the luminance change obtained for square targets using the same photopic probe. The function $C(w)$ also provides insight into the spatial profile of the contribution to the target luminance variation.

4. CONCLUSION

We described an experimental method capable of measuring the spatial extent of the electronic crosstalk artifact in high-resolution AM-LCDs using a luminance probe with very low light leakage. We presented data on the horizontal and vertical crosstalk response functions showing that crosstalk effects are most important for distances smaller than 10 mm or about 40 pixels. The long-range crosstalk effect is an order of magnitude smaller than the degradation in contrast caused by veiling glare in high-performance monochrome CRTs. The results confirm that when compared to the effect of veiling glare in CRTs, the degradation of the minimum luminance of small spots caused by crosstalk in AM-LCDs is not significant at large distances but remains important at short distances. Further investigations are needed to determine if the measured short-range crosstalk is due to electronic phenomena, or it is rather associated with local scattering of light in a thin transparent faceplate, sometimes called halation, as suggested in Ref. 12.

5. ACKNOWLEDGMENTS

The authors acknowledge useful discussions on the method with M. J. Flynn (Henry Ford Health System, Detroit, MI). This work was partially supported by a U.S. Army Breast Cancer research grant (BC991150).

REFERENCES

1. Flat Panel Display Measurements Standard Working Group Video Electronics Standards Association. Flat Panel Display Measurements Standard, Version 1.0. Technical report, VESA, May 1998.
2. K. Schleupen, P. Alt, P. Andry, and S. Asaad. High-information-content color 16.3"-desktop-AMLCD with 15.7 million a-Si:H TFTs. *Proceedings of the International Display Research Conference*, pages 187–190, 1998.
3. F. R. Libsch and A. Lien. A compensation driving method for reducing crosstalk in XGA and higher-resolution TFT-LCDs. In *Digest of Technical Papers*, pages 253–256. Society of Information Display, Santa Ana, CA, 1995.
4. F. R. Libsch and A. Lien. Understanding crosstalk in high-resolution color thin-film-transistor liquid crystal displays. *IBM Journal of Research and Development*, 42(3/4):467–479, May 1998.
5. Y.-C. Jeong, C.-C. Park, and L.-S. Kim. A new crosstalk compensation method in line inversion TFT-LCDs. *IEEE Transactions on Systems and Circuits*, 44:552–555, 1997.
6. S. L. Wright, S. Millman, and M. Kodate. Measurement and digital compensation of crosstalk and photoleakage in high-resolution TFTLCDs. In *SPIE Proceedings of the 1999 Flat Panel Display Technology and Display Metrology Conference*, volume 3636, pages 200–211, 1999.
7. D. Braun. Crosstalk in passive matrix polymer LED displays. *Synthetic Metals*, 92:107–113, 1998.
8. A. Badano, M. J. Flynn, E. Muka, K. Compton, and T. Monsees. The veiling glare point-spread function of medical imaging monitors. In *SPIE Proceedings of the 1999 Medical Imaging: Image Display Conference*, volume 3658, pages 458–467, 1999.

†Note that this assumption does not imply that $C(w)$ is linear with respect to I_o.

9. A. Badano, M. J. Flynn, and J. Kanicki. Small spot contrast measurements in high-performance displays. In *Proceedings of the Society for Information Display*, pages 516–519. Society of Information Display, Santa Ana, CA, 1999.
10. A. Badano and M. J. Flynn. Method for measuring veiling glare in high performance display devices. *Applied Optics*, 39(13):2059 – 2066, May 2000.
11. M. J. Flynn, D. C. Wang, A. Badano, and W. R. Eyler. Display quality evaluation. *Radiology*, 213(P):582, November 1999.
12. A. Badano and M. J. Flynn. Monte Carlo modeling of the luminance spread function in flat panel displays. In *Proceedings of the International Display Research Conference*, pages 382–385. Society for Information Display, Santa Ana, CA, 1997.