POLYGONIOSCOPE a new instrument for fastest luminance, color and viewing angle measurement with highest accuracy

Juergen Laur
AUTRONIC-MELCHERS, 76229 Karlsruhe, Germany
TEL:49-721-96264-45, e-mail: laur@autronic.melchers.de
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Abstract

This paper introduces a novel display measuring instrument that allows accurate, spectro-radiometric measurement of the complete viewing cone while the measuring time is similar to that of a CCD camera with transform lens optics. Actually the new instrument, named POLYGONIOSCOPE, is orders of magnitude faster compared to a conventional spot spectrometer.

1. Introduction

The gaining popularity of FPD TVs and the broad variation in the *picture quality* of different displays and technologies require a valuable measure of the display characteristics. Even though it is not surprising that measuring "motion blur" caught soon attention in the display community when introduced in 2004 [1], it is surprising that another even more significant measure of picture quality got totally out of the focus and is just now coming back on the agenda: the "viewing angle".

In terms of motion blur it usually requires a side by side comparison of good and bad examples in order to recognize the performance of the superior display. Motion blur can be strongly improved by data processing or controlled backlight units (BLU). Further on, latest findings show that motion blur in displays using state of the art technology is mainly caused by the source material (signal) rather than the display itself [2].

Things are different in terms of viewing angle. Liquid crystal displays show an intrinsic variation of transmission against viewing direction. This is well understood since their earliest days and respectively a measure called "viewing angle" has been used for characterizing the *readability* of a still image at the time when the content of those monochrome displays was numerical or textual information. Nowadays, displays and content have changed from black-white text to colorful videos and respectively *readability* is not a sufficient and suitable quality criterion any longer. While the typical consumer and display user may understand the "viewing angle" as the range of viewing directions from which the display can be observed without any 'significant' variation of the image quality, a common but not standardized definition for the "viewing angle" used by display manufacturers is a contrast ratio of 10 which is only measured in horizontal and vertical direction.

This criterion is neither based on ergonomics nor on any other finding which is meaningful for video displays. It seems to be a relict of the early days when FPDs showing static black-white (b/w) images such as text or numbers as printed paper does. The luminance contrast ratio (CR) of newspaper is typically 10 to 20. It seems therefore natural to use printed paper like image quality, i.e. CR=10, as a benchmark for those first b/w LCDs and apply this criterion for the "viewing angle" definition. This is no longer appropriate for current display applications and technologies. Further on, the limitation of the display industry's "viewing angle" to horizontal and vertical direction is not reasonable for various reasons.

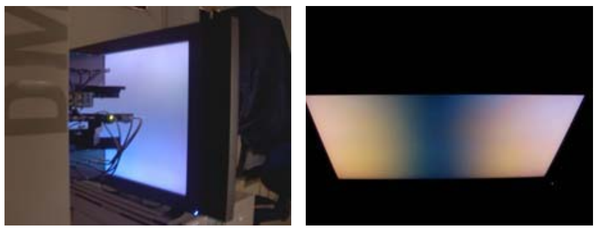

Figure 1: Black state of a LCD TV set captured with still image camera from horizontal and vertical direction. Black appears only black along the vertical. "Viewing angle" according to current definition: 176°.

requirements: accurate luminance and color measurement of the full viewing cone in a reasonable time, i.e. few minutes.

This goal has been achieved by an all-new approach called POLYGONIOSCOPE. This instrument contains up to 10 spectro-radiometers and thus covers a cross section for the angle of inclination (Theta) from 0° up to 88°. The detectors are equally spaced mounted in a 10degree step up to 80° plus a flexible tenth as shown in Fig.2. The spectra from those 10 directions are recorded simultaneously.

For accurate color measurements the spectro-radiometers feature a spectral bandwidth of 3nm full width at half maximum (FWHM). The spectral bandwidth describes the instruments response to monochromatic light which is represented by an ideal peak, comparable to a system's impulse response to a Dirac delta function (1) in signal processing.

$$\delta(\lambda) = \begin{cases} +\infty, & \lambda = \lambda^* \\ 0, & \lambda \neq \lambda^* \end{cases} \quad (1)$$

$$\text{with} \quad \int \delta(\lambda) \cdot d\lambda = 1$$

In first order, the impulse response of a spectrometer can be described as an (isosceles) triangle.

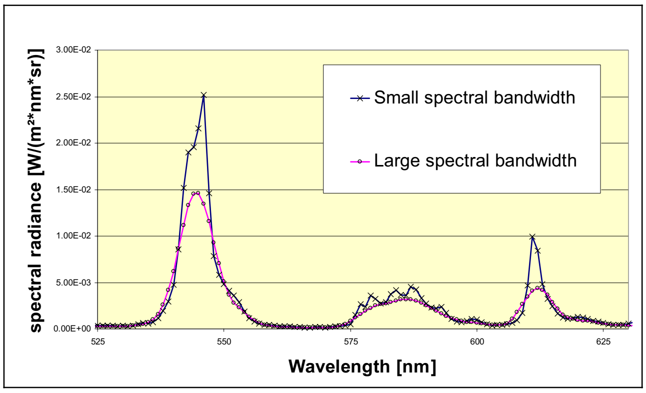

Figure 4: Spectra from 525nm to 625nm of a LCD with CCFL backlight measured with spectrometers with small (2nm FWHM) and large (5nm FWHM) spectral bandwidth. The resolution and respectively the result in terms of luminance and color are obviously different. The luminance error of the 5nm FWHM is 16% on CCFL (graph) and 0% on A-type (not shown)

The spectral bandwidth describes the difference between the two wavelengths at which the intensity is equal to half of its maximum value, the full width at half maximum. (Fig.3). It is obvious that for smooth, broad spectra such as emitted by an A-type source, the impulse response, i.e the spectral bandwidth is not of high importance. While for typical FPD measurement the spectral bandwidth is outmost crucial (Fig.4). This means in practice that even though two spectrometer show identical luminance and color values when measuring an A-type light source, there might be an error of more than 15% in luminance on the instrument with large spectral bandwidth when measuring a CCFL or LED spectra.

Wavelength accuracy is another important issue for accurate color and luminance measurement besides the spectral bandwidth. In order to assure good wavelength accuracy the system needs to be calibrated and verified not only at a single wavelength but over the full visual spectrum. Fig.5 shows a comparison of a spectro-radiometer with wavelength calibration over full range of visible light and another detector which is not calibrated at wavelengths below 435nm.

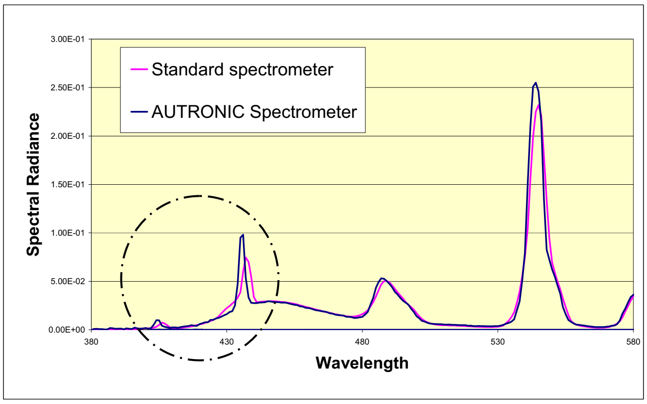

Figure 5: Spectra from 380nm to 580nm of CCFL. The standard spectrometer shows significant wavelength errors below 435nm.This yields in an error of 0.01 in color value y.

3. Full display characterization in minutes

New industry standards require fast and accurate measurement of color vs. viewing direction. Using the POLYGONIOSCOPE of AUTRONIC-MELCHERS, a 42" TV set could be fully characterized in terms of viewing angle dependency and color gamut in less than 10minutes comprising white, black, red, green and blue covering the full hemisphere, i.e. Theta 0 to 88° and Phi 0 to 360°. The angular resolution was 10 degree in azimuth as well as in inclination.

First of all, the display user will look at the full screen and not only at a single spot. Respectively, even if the user is located in center position of a screen a composition of viewing directions will be observed at a time of which the majority is neither in horizontal nor in vertical direction, see Fig.1. Second, such a limitation creates unsuitable results as common technologies such as vertical alignment (VA) and in-plane switching (IPS) are optimized for horizontal and vertical contrast but show significant contrast reduction in other than those directions. As a conclusion the horizontal and vertical "viewing angle" derived from contrast ratio is actually meaningless. Even worse, this "definition" cumbers technology development as any of current IPS, VA or even compensated TN technologies exceeds a CR of 10 @ Theta 80°. Therefore, the current "viewing angle" specification will tell the non-professional display user that the performance is similar for all LCDs, e.g. ±85°, independent of the applied technology. Do we, the display community, expect the common user to understand that this is only specmanship, not related to image quality and in fact reality?

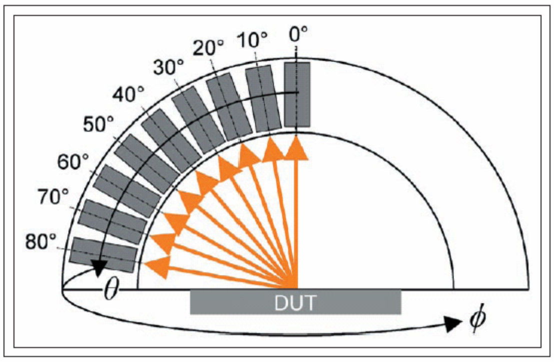

Figure 2: POLYGONIOSCOPE: A multi-channel spectro-radiometer is recording the spectra from various directions simultaneously.

The perceived image quality is a composition affected by motion blurring and static image quality such as resolution, luminance level, luminance dynamic, i.e. contrast, and color. While resolution does not change with the viewing direction, luminance and color do so. In particular color shift is an undesirable effect and perhaps the most annoying and limiting factor for a customer defined "viewing angle". As a matter of fact, current discussions in ICDM (formerly known as VESA standard) stress this topic and it seems there is a common agreement in the display community to define a more realistic "viewing angle" where color may have the dominant role and eventually accurate color measurement over the full viewing angle will become indispensable.

2. Methods for Color Measuring

So far, two measuring principles have been established for angular resolved measurement:

- goniometers with either spectrometer or colorimeter and
- imaging systems with a CCD camera and special transform lens system which captures the hemispherical emission of the display up to an angle of 80° or 88° in one shot.

The latter instrument is a colorimeter or low resolution spectrometer (optical bandwidth >8nm). For accurate color measurement colorimeters and low resolution spectrometers are no suitable instruments due to their intrinsic lack in accuracy with different spectra (such as peak-like CFL and LED) as they are common with FPD applications [3].

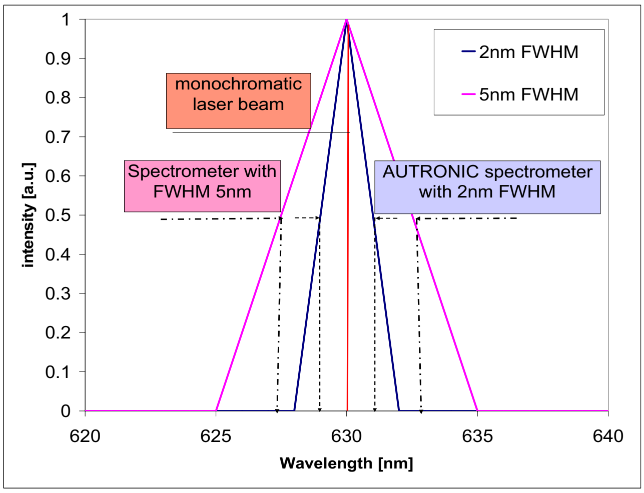

Figure 3: Spectral bandwidth is the response of a spectrometer to an ideal peak signal. This figure shows the impulse response of a spectrometer with 2nm FHWM and 5nm FHWM respectively.

On the other hand, common goniometers with accurate spot spectro-radiometers require a measuring time which may take hours for a full hemispherical scan.

In order to meet industry's demand, a new instrument has been developed which fills both

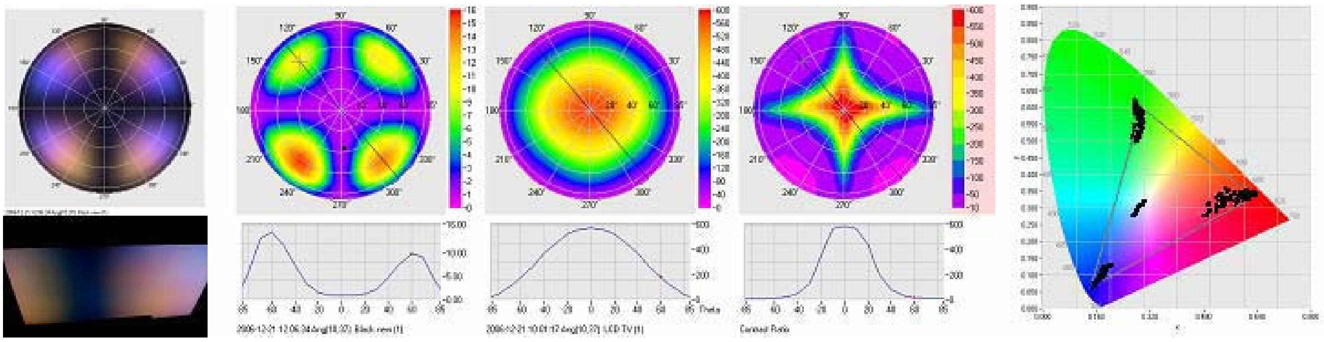

Figure 6: Typical measurements required for a meaningful "viewing angle" definition such as luminance variation, contrast and color can be performed in about 6 minutes with the POLYGONIOSCOPE. High color accuracy is assured under any angle.

The measurement accuracy of the DMS 1100, as a representative of the polygonioscopic family, has been confirmed for accurate low luminance measurement of down to typ. 0.02cd/m2

4. Summary

Exact color representation of TV, monitor and laptop displays is crucial for the consumer. Therefore improvement of color shift over viewing direction is one of the hottest topics the display industry is currently working on.

New display technologies and approaches such as doubling the amount of subpixels (8domain LCD) in order to improve viewing cone characteristics require an appropriate instrument that can measure color accurately. We have shown that spectrometers with a large optical bandwidth are not suitable for display measurement. Only spectrometer with small optical bandwidth, we recommend 3nm, will give trustworthy results. Further on, wavelength accuracy over the full range of visible light is essential.

Both topics have been carefully considered during the design of the POLYGONIOSCOPE series such as DMS 1100 and DMS 1200. The extreme short measuring time in combination with a fully automated measurement sequencer and report generator of the display measuring systems (DMS) allow highest throughput. In order to assure full display qualification, a fast photodetector for response time measurement is integrated, too.

The POLYGONIOSCOPE meets the industry's demand for much faster but at the same time more accurate data and therefore supports the display industry in shifting from the current 'no-meaning' definition of "viewing angle" to a specification that meets industry and consumer demands at the same time.

5. References

[1] Igarashi, T. Yamamoto, Y. Tanaka, J. Someya, Y. Nakakura, M. Yamakawa, S. Hasegawa, Y. Nishida and T. Kurita, Proposal of the Perceptive Parameter Motion Picture Response Time (MPRT), SID '03 Digest of Technical Papers, p. 1039 (May 2003)

[2]F. v. Heesch and M. Klompenhouwe, The Temporal Aperture of Broadcast Video, SID'08 Technical Digest, 26.4 (2008)

[3] Y. Zong and Y. Ohno, Spectral Color Measurements, NIST Homepage, May 2007