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Limitations of visual gamma corrections in LCD displays

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ABSTRACT

A method for estimating the non-linear gamma transfer function of liquid–crystal displays (LCDs) without the need of a photometric measurement device was described by Xiao et al. (2011) [1]. It relies on observer's judgments of visual luminance by presenting eight half-tone patterns with luminances from 1/9 to 8/9 of the maximum value of each colour channel. These half-tone patterns were distributed over the screen both over the vertical and horizontal viewing axes. We conducted a series of photometric and psychophysical measurements (consisting in the simultaneous presentation of half-tone patterns in each trial) to evaluate whether the angular dependency of the light generated by three different LCD technologies would bias the results of these gamma transfer function estimations. Our results show that there are significant differences between the gamma transfer functions measured and produced by observers at different viewing angles. We suggest appropriate modifications to the Xiao et al. paradigm to counterbalance these artefacts which also have the advantage of shortening the amount of time spent in collecting the psychophysical measurements.

1. Introduction

Liquid–crystal displays (LCDs) are the dominant technology for displaying visual information nowadays. They have become so due to their relative inexpensiveness, low power consumption and convenient screen-size to total-volume ratios. In consequence, LCDs are available at increasingly larger sizes, with image quality characteristics (e.g. colour gamut maximum luminance, contrast ratio and spatial resolution) that usually exceed those of the formerly dominant *cathode-ray tube* (CRT) technology [2].

However, with the increasing popularization of LDC technologies there is also an increased need for more accurate colour management. For this reason, *display characterization* [3] is an essential step for accurately controlling the colour of displayed images. In this regard, CRT monitor technology has been extensively studied in the past both in terms of their colour characteristics [4,5] and calibration techniques [6,7], including those that rely on visual comparison instead of a photometer [8]. On the other hand, corresponding LCD colour characteristics and calibration methods have started to be reported much later [1,2,9].

The characterization of a display usually involves two stages [4]: (a) modelling the non-linear relationship between the electrical signals used to drive the display and the radiant output produced by each of the display's chromatic channels, and (b) modelling the linear transformation that converts the device-dependent RGB output to a device-independent tristimulus space (e.g. CIEXYZ). The relationship described in (a) is termed the *opto-electronic transfer function* (OETF). In the case of CRT monitors, the OETF is usually determined by the physics of the display and can be modelled as a power function with an exponent commonly labelled "gamma" (and hence the function is sometimes called the "gamma" function) [6,7]. In the case of LCD displays the OETF is much more difficult to determine, in part because of the more complex physics and in part because of the tendency for manufacturers to account for suboptimal voltage-lightness relationships by remapping it via look-up tables [2]. In addition, backwards-compatibility issues constrain LCD manufacturers to mimic the performance of older CRT displays, regardless of the physical differences between both technologies.

The main problems hampering the performance of LCD monitors and introducing noise in the determination of their OETF are [10]: (a) leakage of light in the OFF state of an LCD, (b) colour and brightness variations as a function of viewing angle and ambient light (c) OEFT dependency on material and cell structure parameters (d) measurement errors introduced by instruments sensitive to light polarization (e) chromaticity variations with

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luminance (light leakage) (f) cross-talks between neighbouring pixels (g) dependency of display characteristics with temperature (h) need for measurement instruments to capture the narrow-band fluorescent lights used as LCD light sources (i) complex reflection of ambient light from the display screen.

1.1. LCD technology

Fig. 1 shows the schematics of a pixel element inside one of the most common LCD types, the backlit *Twisted Nematic* (TN) LCD [11–13]. The light is usually produced by LEDs or fluorescent elements and a mosaic of R, G and B filters is aligned to the substrate glass producing coloured cells that are controlled independently, so that the human visual system integrates their light in the same way as it does for CRT monitors. For this reason, most CRT colour models hold for LCDs if we assume the same sort of channel independence [9]. However, the OETF of an LCD pixel cell tends to be a sigmoid (S-shaped) function, which is quite different from the usual "gamma" power function of CRT monitors. To allow for backwards compatibility, LCD monitors share some of the characteristics of CRTs such as R, G and B chromaticities and inbuilt tone-response compensations to mimic the power-law relations present in CRTs.

TN displays suffer heavily from the unintended activation of non-addressed pixels (crosstalk) and need some kind of additional non-linear electronic elements into each pixel cell, e.g. thin-film diodes, or transistors applied to individual picture elements in order to avoid it. There is also a well-known dependency of the OETF of individual cells with viewing angle [2].

Another popular LCD technology is termed *Vertical Alignment* (VA) [14–17]. The main difference with TN technology is that when no voltage is applied, the liquid crystals do not allow the passage of light through the crossed polarisers (see Fig. 1). Given that their natural state is to block light, VA monitors provide good black depth. The OETF is again dependent on the viewing angle, but there is no reason for its dependency to be the same from that of TN displays.

A third popular LCD technology is called "*In-Plane Switching*" (IPS) [18,19]. It was invented in the 1970s and applied to large LCD panels in the 1990s as a way to improve on the poor viewing angle and the poor colour reproduction of TN panels. It owns its name to its main difference from TN panels: the electric field is applied parallel to the panel plane instead of perpendicular to it. In this arrangement, crystal molecules are aligned parallel to the panels in the ON state, reducing the amount of light scattering in the matrix, which arguably gives IPS much better wide viewing angles and good colour reproduction.

1.2. Perceptual gamma correction methods

The precise modelling of the OETF is likely to require a photometer with the corresponding cost and relatively higher degree of user expertise. However, a simpler (and cheaper) "perceptual" alternative has been developed and successfully used in CRT [8,20,21] and LCD [1,22] characterization, and in the case of CRT displays, there are several commercial gamma correction software available, e.g. Adobe Gamma (Adobe San Jose CA, US) and EasyRGB (http://EasyRGB.com).

These "perceptual" gamma correction methods require an observer to match a typical half tone pattern (composed by pixels either "black" or at peak value so that their average luminance is a known fraction the maximum luminance) to a uniform luminance patch. The paradigm relies on a perceptual illusion: that these small halftone pixels are blended into smooth tones by the human vision system. If we assume that the OETF is well described by a power function (as is the case in CRT monitors) we need only one mid-tone measurement per chromatic channel to model it. However, given the more complex nature of LCD displays, observer variability and the factors mentioned above, more "half-tone" pattern matches are typically needed to model LCD displays. In the particular method devised by Xiao et al. [1] eight different half-tone patches were used to generate the data points needed for modelling the OETF in each chromatic channel. These patches (3×3 pixel blocks) were set to average luminances equal to 1/9, 2/9, 3/9, 4/9, 5/9, 6/9, 7/9 and 8/9 of the maximum display

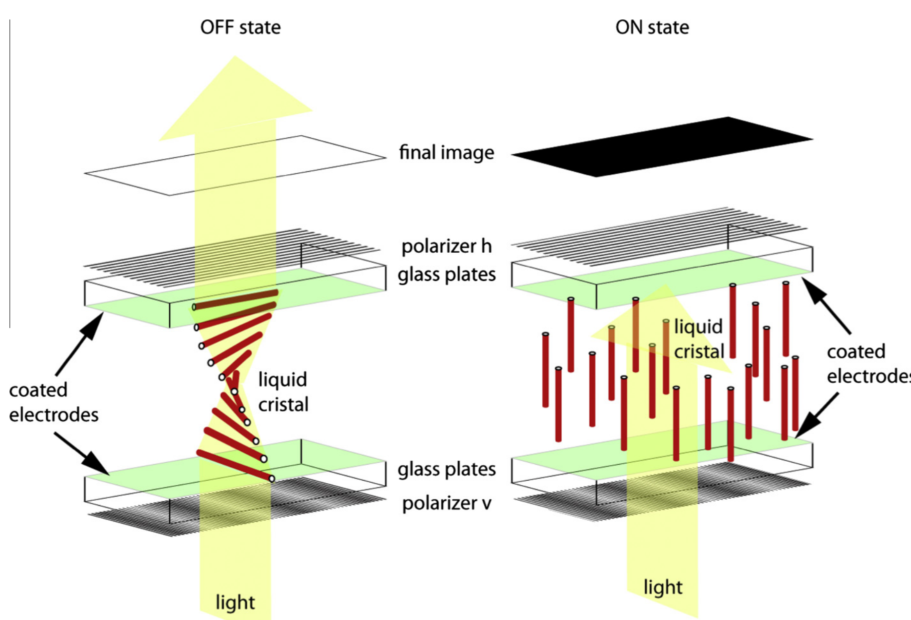

Fig. 1. Schematics of a Twisted Nematic (TN) pixel element (cell). The left part of the figure represents the cell's OFF state, where no voltage is applied to the electrodes allowing the light from the light source (e.g. LED backlighting or cold cathode fluorescent backlighting) to arrive to the observer's eye. The right part of the screen represents the ON state, where a voltage is applied to the electrodes resulting in most of the light to be blocked by the two orthogonally oriented polarisers.