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Low-Cost Method to Improve Viewing-Angle Characteristics of Twisted-Nematic Mode Liquid-Crystal Displays

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Abstract

By processing pixel data, a low-cost halftone method is proposed to improve viewing-angle characteristics of TN-mode TFTLCDs. The algorithm reduces the occurence of pixels in natural images with mid-tone graylevels, preserving the local luminance. The improvement in viewing-angle characteristics occurs with some loss of image detail. As the pixel density is increased, the halftone pattern becomes less noticeable.

1. Introduction

The liquid crystal mode used in most notebook computer TFTLCDs is Twisted-Nematic (TN) mode. Viewed off-axis, this mode exhibits poor viewing angle characteristics, with color shifts and contrast reversal dependent upon viewing angle. For viewing angles close to normal incidence, the luminance follows a power law with digital pixel level, roughly following a power law referred to as the gamma curve. The luminance of the bright state falls off gradually for off-axis viewing angles. At low digital pixel levels, the luminance varies strongly with viewing angle, particularly for viewing azimuths in the up/down (vertical) direction. For some viewing directions, these characteristics have poor image quality, with distorted gamma curve, loss of contrast, or contrast reversal. For images containing a mixture of bright and dark pixels, the variation in dark state luminance is not very noticeable, relative to the bright state. For most images the strongest relative variation in luminance versus viewing angle occurs for middle range of pixel values somewhere between the dark state and bright state.

Several methods have been used to ameliorate these undesirable TN-mode characteristics, without changing liquid-crystal mode. Ohi et al. [1] describe a technique that provides a new set of analog reference voltages to the data drivers every other frame. Ikezaki et al. [2] describe a technique whereby the reference voltage set is altered such that the lowest reference voltages are increased to suppress level reversal. Alternatively, a split pixel structure has been used [3-6] with different load capacitances to provide different voltages to the two subpixels, described as a "halftone gray-scale method". Ogura, et al. [7] describe a technique by using additive gray-level mixture driving, where odd column pixel voltages are different from even column pixels. This work describes an alternative, low-cost halftone method [8] to achieve improved viewing angle characteristics of TN-mode TFTLCDs with pixel data processing.

2. Method

For images containing a mixture of pixel values, the variation of the darkest pixel luminances with viewing angle is not very noticeable, relative to the brightest pixels, if the observer has adapted to either the display white state or a moderately bright surround ambient light. The bright state luminance is inherently uniform for most liquid crystal cell designs. For most images the strongest relative variation in luminance versus viewing angle occurs for middle range of pixel values somewhere between the dark state and bright state. Luminance variations with viewing angle leading to contrast reversal are very noticeable. The viewing angle characteristics can be improved by providing an equivalent halftone image, in which the number of pixels with mid-level values is reduced. Retaining the full graylevel capability of the display, these halftone patterns are very different from halftone patterns and algorithms used in print, where there is little or no inherent grayscale capability.

In a simple implementation, the average luminance of an adjacent vertical pair of subpixels is calculated via a lookup table (LUT) of the relationship between luminance and digital level. The LUT is then applied in reverse to determine a target digital level which could be applied to both subpixels to obtain the same average luminance. From this target digital level, a pair of subpixel digital levels is then generated, with one high value and one low value. Over all target values, a bright branch of high values and a low branch of low values can be created. There are many possible algorithms for the choice of bright and dark branch values. Initially, it was thought that the best choice would be to separate the bright and dark branches as far as possible, shown as the "linear" algorithm in Fig. 1. This choice resulted in undesirable image artifacts, including luminance banding, and other errors in reproduction of the original luminance. After a number of trials with other candidate functions, a simple power-law relationship was found to exhibit acceptable characteristics. Consider 8-bit drive, with luminance following a gamma curve, where Y is the luminance of a subpixel with digital level n, and the luminance of the dark state is negligible:

$$Y = Ymax\,(n / 255)^{\gamma}$$

For each pair of subpixels with digital values n_1 and n_2 , the average luminance is $(Y_1 + Y_2)/2$, and a target digital value (n_t) for the pair is calculated as

$$n_t = 255\,((Y_1 + Y_2) / 2Ymax)^{1/\gamma}$$

For a power-law halftone relationship with exponent p, the dark branch of the halftone subpixel pair is given by

$$n_d = 255\,(n_t / 255)^{p} = 255((Y_1 + Y_2) / 2Ymax)^{p/\gamma}$$

where n_d is the digital level of the dark subpixel. From the target and dark subpixel luminances, the luminance of the bright subpixel can be determined. The digital values of the bright branch, n_b , are then:

$$n_b = 255\,[\,2(n_t / 255)^{\gamma} - (n_t / 255)^{p\gamma}]^{1/\gamma}$$

As p is increased, the separation between the dark and bright branches is increased, and the viewing angle characteristics are improved. However, as the power p is increased beyond a threshold value, a luminance error is introduced for the highest

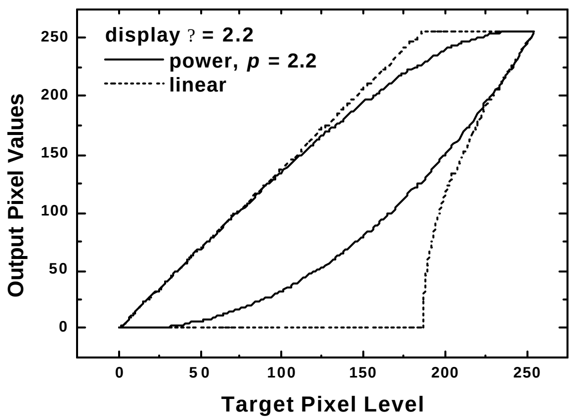

Figure 1. Bright and dark pixel values versus target pixel level for linear- and power-law algorithms.

digital pixel values near level 255. It was empirically found that a value of $p \sim \gamma$ resulted in the substantial improvement in viewing angle characteristics with acceptable error. Fig. 1 illustrates the power-law relationship between target digital pixel level and dark and bright halftone pixel levels for a gamma of 2.2. With modifications to include the detailed luminance characterics of a panel, a similar formula can be used to generate values for a LUT.

The suitable halftone patterns must satisfy two conditions. First, to minimize flicker, the pattern must balance the number of positive and negative bright subpixels for the drive inversion condition. This requirement stems from the fact that the push-down pixel voltage, ΔV_p, is usually different for positive and negative frames due to the different bias and TFT parasitics during chargeup in the different polarity frames. Typically, high-end TFTLCD panels are driven under dot inversion, in which the pixel polarity alternates by both subpixel column and by row in a subpixel checkerboard pattern. A simple full-pixel checkerboard pattern, such as that used for the shut-down screen in windows, or as a transparency layer in drawings, does not satisfy the first condition and visible flicker can result if the image contains uniform regions of mid-tone digital values. Second, the pattern granularity must be minimized to reduce the visibility of the pattern itself. For standard display resolutions in the range of 100 ppi, full-pixel or larger patterns are too coarse to be acceptable. The detailed horizontal and vertical pattern characteristics also affect pattern visibility for different images. Two of the simplest halftone patterns for dot inversion are shown in Fig. 2 and Fig. 3.

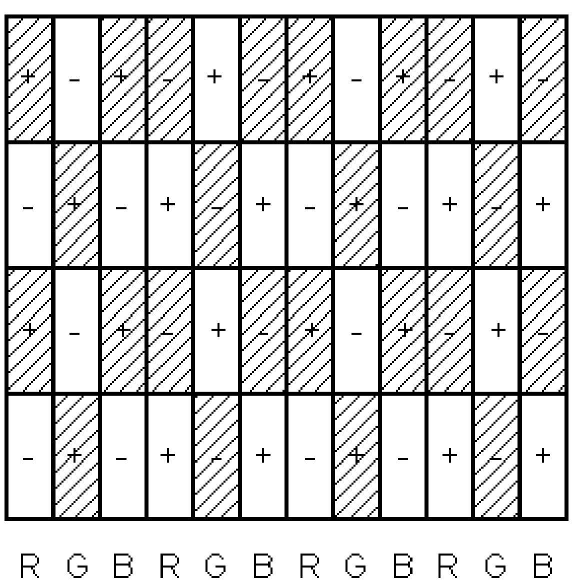

Figure 2. 2x2 Subpixel green/magenta subpixel pattern.

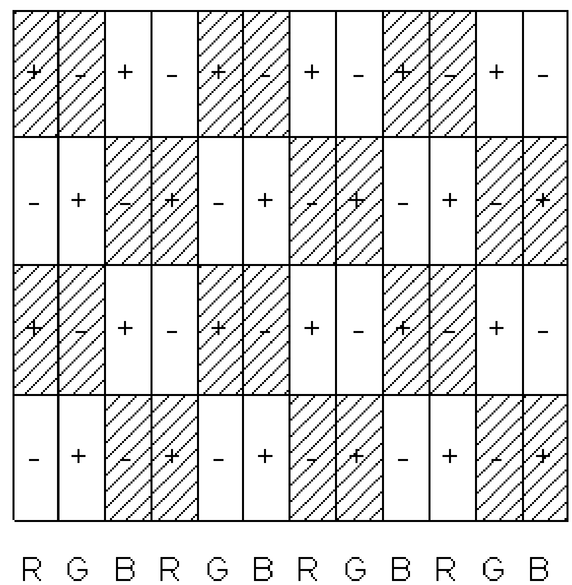

Figure 3. 4x2 Double subpixel pattern.

The algorithm can be implemented in software, graphics hardware, or display hardware. For the simplest patterns, the input subpixel values for the calculation are processed in pairs of rows, and aside from the LUT, the mathematical operations are addition and divide by two. The calculation can be performed in hardware with a line buffer, minimal storage of intermediate results, and at pixel input rates. The algorithm can also be constructed in such a way that the halftone process is turned off for portions of an image which contain blocks of pixel values which are saturated at very high or very low digital pixel levels, such as would occur with rendered text. The algorithm can also be constructed to pass subpixel-antialiased text letters with acceptable alteration.

The input pixel data could be processed in blocks larger than the horizontal pairs shown here. This further improves the viewing angle characteristics at the expense of additional processing and further loss of image detail.

3. Results

To demonstrate the method, a software program was created to process a bitmap image. For XGA image sizes, the program required a few seconds to run. The processed halftone images were then subjectively compared with the original images to judge the overall improvement in viewing angle characteristics. For some choices of halftone algorithm parameters, luminance banding, changes in hue, or luminance errors for high or low digital pixel levels were evident. The best overall results were obtained for the power-law halftone method previously described. The improvements in viewing angle are primarily in vertical azimuths, especially when the viewing direction is from below where contrast reversal effects are strongest.

In a polar plot of TN-mode luminance verus viewing angle, for digital pixel levels near 255, the luminance has a peak close to on-axis. As the digital pixel level is decreased, the luminance peak shifts in a vertical azimuthal direction, corresponding to viewing from above, creating "washed-out" image characteristics. For viewing from below, the sharp changes in luminance versus level, create image characteristics with contrast reversal.

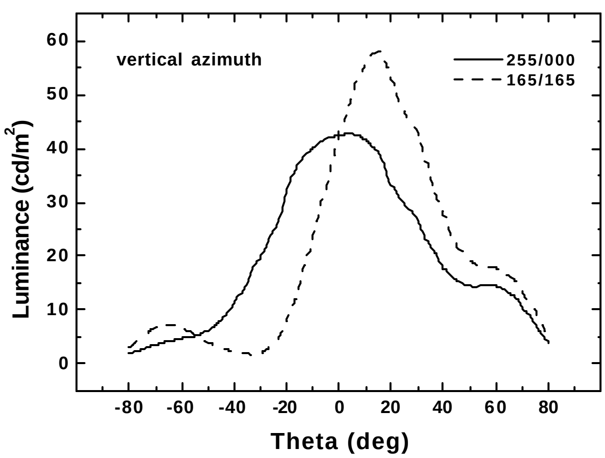

Figure 4. Luminance versus vertical viewing azimuth for uniform gray and checkerboard patterns.

The halftone pattern centers the peak luminance close to on-axis for low digitial pixel values, and this improves the range of viewing azimuths without contrast reversal. The halftone pattern also increases the width of the luminance peak. Fig 4 shows a luminance profile in the vertical azimuth over incident viewing angle for two conditions: a uniform gray at level 165 and a halftone checkerboard pattern of levels 0 and 255, matching the luminance of level 165 at normal incidence. The peak luminance of the halftone pattern is centered at normal incidence, and the full-width half-maximum for luminance distribution is 18 degrees larger for the halftone pattern than for the uniform pattern.

Tests were performed on panels with pixel densities of 96 ppi, 133 ppi, 157 ppi, and 204 ppi. Improvements in viewing angle characteristics were the same for all pixel densities, but the appearance of the halftone pattern granularity reduced with increasing pixel density. At 204 ppi, the halftone pattern was hardly noticeable, and the overall appearance of the halftone image was similar to continuous images on 96 ppi panels. For many static image applications, the quality of the halftone image pattern should be acceptable for pixel densities in the range of 170 ppi and greater. For applications with moving pictures, such as digital video disk movies, the image quality may be acceptable at a much lower pixel density, perhaps as low as 100 ppi. For most images, the 2x2 subpixel halftone pattern produced superior results to the 4x2 double subpixel pattern and other candidate patterns. Fig. 5 is a photograph of two side-by side images, with and without halftone processing for a 2x2 subpixel pattern, taken at an incident angle of approximately 30 degrees below normal incidence. The uniform image exhibits contrast reversal, but the contrast reversal is largely suppressed in the halftone image.

4. Conclusions

A low-cost alternative approach has been devised to improve viewing angle characteristics of high resolution TN-mode TFTLCDs, as compared to methods requiring other liquid crystal modes and/or changes in drive electronics. An initial proof of concept has been demonstrated using processed bitmaps.

Figure 15. Photograph of side-by-side processed hafltone image and unprocessed image on TN-mode LCD.

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6. References

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