High Dynamic Range Display System

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Abstract

We have developed a high dynamic range (HDR) display capable of presenting a luminance range of 10,000 cd/m^2 to 0.1 cd/m^2. In addition to the initial embodiment of the technology, we have developed a flat-panel version using light emitting diodes (LED) which offers the same dramatic dynamic range benefits in a much smaller package.

Conventional Liquid Crystal Display Technology

In a conventional liquid crystal display (LCD), two polarizers and liquid crystal are used to modulate the light coming from a uniform backlight, typically a fluorescent tube assembly. The luminance level of the light emitted at each pixel is determined by the polarization state of the liquid crystal and it is important to point out that an LCD cannot completely prevent light transmission - even in the darkest state of a pixel, light is emitted and as such the dynamic range of an LCD is defined by the ratio between the light emitted at the brightest state and the light emitted in the darkest state. For a high quality LCD, this ratio is usually around 300:1. In order to maintain a reasonable 'black' level of about 1cd/m^2, the LCD is limited to a maximum brightness of approximately 300cd/m^2.

Conventional displays are thus unable to show the true dynamic luminance range we observe in real life. For instance, a typical fluorescent light fixture has a luminance of approximately 4000cd/m^2, and objects illuminated by the sun can easily exceed 10,000cd/m^2.

High Dynamic Range Display Technology

The basic modification introduced by the HDR technology involves inserting a second light modulator and increasing the brightness of the backlight. Using two modulators (e.g. two LCD) reduces the light emission in the dark state and thus the brightness of the backlight can be increased without losing the 'black' state. Optically, this series of modulators acts as a multiplication of the dynamic range of each modulator. For the first embodiment of the HDR display presented in this paper, the backlight and the first modulator are combined into a single digital video projector. The three central components of the HDR display are the projector, the LCD and the optics coupling the two. Each image on the HDR display is the result of modulated light coming from the projector which is then directed onto the rear of the transmissive LCD by the optics system, modulated a second time by the LCD, and finally diffused for viewing.

The projector used in the HDR display is an Optoma DLP EzPro755 digital mirror projector. To reduce unnecessary light loss, we have removed the color wheel of the projector, resulting in a monochrome display system with a threefold increase in brightness due to the absence of the color filters. The LCD panel is a 15" laptop LCD made by Sharp (Sharp LQ150X1DG0), driven by an EarthVision AD2 LCD controller.
The optics used in the HDR display are designed to collimate the projected light prior to entering the LCD and then diffuse it over an appropriate viewing angle.

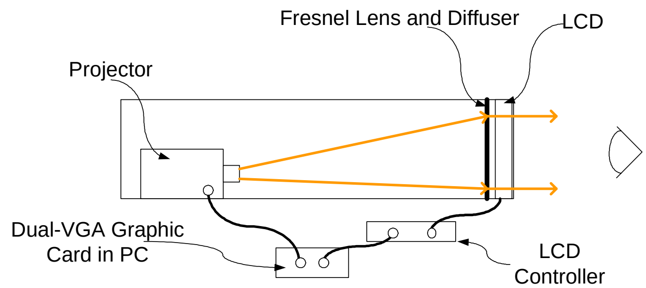

Figure 1: Schematic of the HDR display including the projector, LCD and optics. Both projector and LCD are driven by a single dual-VGA graphic card.

Using this configuration, the light output of each pixel of the HDR display is effectively the result of two modulations, first by the DLP and then by the LCD pixel, along the same optical path. Since both systems have an 8-bit depth, this allows for 255^2 configurations, over 17,000 of which are distinct. Since the DLP has a dynamic range of 400:1 and the LCD a dynamic range of 300:1, the dynamic range of the HDR display is then 120,000:1. The luminance values matching these boundaries are a result of the brightness of the projector and the transmission of the LCD. In this case, the Optoma EzPro755 is rated at 2000 Lumens, or approximately 6000 Lumens without the RGB color filter. The Sharp LCD panel has a measured transmission of approximately 7.6% in the white state. The light emitted by the HDR display is diffused across a solid angle of 0.65 steradians. For these parameters the maximum luminance is just slightly over 10,000cd/m^2 and the minimum luminance is under 0.09cd/m^2. Within that vast dynamic luminance range, over 17,000 distinct levels are distributed non-linearly with increasing step sizes as the luminance increases.

LED-based HDR Display

Further benefits can be obtained by replacing the DLP projector with an active array of high brightness white (or tri-color) LED. The fundamental concept of dual-modulation in series remains the same but now the LED array acts as both the backlight and a first low-resolution modulator since each LED can be current-controlled over at least an 8-bit dynamic range. The blur introduced by the 5mm diameter LED can be compensated for by an appropriate correction of the image on the LCD such that the multiplication of the two layers yields a high resolution, high dynamic range image. The uncorrectable imperfections at very high contrast boundaries on top of a single LED are essentially invisible to the human eye as intraocular scattering causes a much more significant visual imperfection at such boundaries. The use of LED also adds benefits in color gamut increase and motion blur eliminations using standard LED-backlighting methods. Furthermore, due to the much lower resolution of the LED matrix compared to the LCD (less than 1%), a significant reduction in data storage and transport is achieved.