[Forefront]

Frame-Rate Technique Delivers Flicker-Free Motion-Picture Performance

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Researchers at Texas Instruments have de-veloped a digital light-processing (DLP) technique that enables entirely flicker-free cinema. Gregory Hewlett and Gregory Pettitt presented the details at July's Microdisplay 2000 Conference in Boulder, Colo.

Traditionally, film has been recorded at a frequency of 24 Hz. This rate lets viewers experience the effect of motion. But if the film is then projected at the 24-Hz frame rate—well within human flicker sensitivity—audiences perceive severe flicker. To avoid this, film projectors normally shutter at twice this rate (double shutter) by using a 48-Hz refresh rate. This somewhat diminishes the distortion, but viewers still see a considerable amount of flicker during brightly lit scenes.

The researchers at Texas Instruments came up with a technique that takes advantage of the control versatility of the company's digital micromirror device (DMD) technology. It enables the independent control of every bit. Higher-order bits can be refreshed at 96 Hz, while lower-order bits are refreshed at 48 Hz and even 24 Hz. At these rate, viewers perceive no flicker at all.

Flicker is an artifact that makes an image appear to flash rather than retain steady brightness. The minimum frequency at which a modulated source is perceived as steady is known as the "critical flicker frequency," or CFF.

A source output such as a projector can be modeled using a sine wave whose response obeys the equation:

$$f(t) = T_O[1 + m\sin(wt)]$$

where:

$T_O = T_F(1 + 1/CR)/2$, $CR = T_F/T_B$, which is the contrast ratio of the source, T_F = the maximum brightness of the source, T_B = the minimum brightness of the source, and m = the modulation amplitude

The amplitude of the source waveform is governed by the parameter m, where $0 < m < 1$.

A model of the eye's temporal and spatial responses is known as a "contrast sensitivity measure," or S (ω). It's based upon a number of parameters that include target size, adaptation level, and the eye's integration time *(Fig. 1)*. This model is used as the basis for the analysis for the devised technique. In this case, CFF is defined as the frequency at which S (ω) = 1/m *(Fig. 1, again)*. The region down and to the left of the plot is the domain in which flicker is visible, whereas viewers do not detect flicker in the region up and to the right.

The CFF is inversely proportional to the modulation amplitude (CFF = 1/m). Moving upwards at a given frequency, the amplitude becomes smaller until curve S (ω) is reached, passing from the region of *visible* to *not visible* flicker. In other words, the lower the value of m, the less it's likely that viewers will detect flicker.

Projection systems using the DMD as the modulation device generate output in the form of pulses of light. The CFF can be computed for the pulses of light generated by film and DLP cinema projection. Unlike film, which generates various intensity levels with amplitude modulation, the DMD uses pulse-width modulation. The duty cycle of the DMD varies from pixel to pixel, thereby supplying the image to the viewer as it changes at 24 Hz. Yet the refresh rate doesn't have to be confined to 24 Hz. It can be delivered at higher rates, depending on the significance of each bit.

Each single pixel has two intensities—46% and 62.5%—for a single refresh period (1/frame rate) *(Fig. 2)*. Successive bits consume progressively more of the total refresh interval. Each successive bit has twice the previous duration, from the least significant bit (LSB) to the most significant bit (MSB).

A Flicker-Free Rate

Figure 3 illustrates a case where four refresh cycles occur in 1/24 s. This is a refresh rate of 96 Hz (or a cycle time of 1/96 s). If a refresh rate of 96 Hz could be utilized, there would be no flicker. Due to the limitations of the DMD, though, LSBs of 2.5-µs duration would be necessary to achieve 12-bit resolution. But the DMD technology requires that all bits be at least 10 µs in duration. So, there is a tradeoff between the operating refresh rate and the length of the LSB. If the operating refresh rate is too high, the LSB becomes too short. Likewise, if the operating refresh rate is too low, viewers detect flicker.

The solution lies in the fact that each bit is displayed entirely independently from every other bit. The DLP electronic system has been designed so bit sequences are programmable according to an independent bit-by-bit specification. Users are free to display the given bits of the 24-Hz source so the MSBs can be shown at multiples of 24 Hz (48, 72, or 96 Hz or greater), while the LSBs can be shown at a refresh rate as low as 24 Hz.

Using the temporal sensitivity model, each of the bit durations can be mapped on the sensitivity curve *(Fig. 4)*. The 10-µs pulses can operate at 24 Hz to avoid flicker, whereas a 200-µs pulse would have to be refreshed at 48 Hz or higher to be flicker-free.

Frame-rate by bit-significance, from LSB to MSB, is tabulated in the table. Bits of successively longer durations need to be refreshed at the higher bit rates to prevent flicker.

Moviegoers may be used to flicker. But the DLP projector provides, for the first time, a solid perceived image that gives audiences a flicker-free cinematic experience. For more information, go to *www.ti.com/dlp* or *www.dlpcinema.com*.