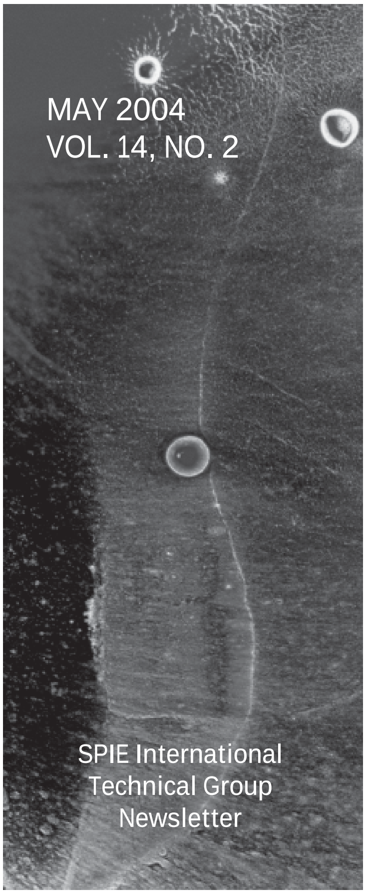

Some of the photos and figures here are available in color in the electronic version of the newsletter. To download, please go to `http://spie.org/web/techgroups/ei/pdfs/ei14-2.pdf`

ELECTRONIC IMAGING

LCoS microdisplays for projection television

LCoS (liquid crystal on silicon) microdisplays are, unlike the active-matrix liquid-crystal displays (LCDs) found on notebooks, reflective. As shown in Figure 1, they are built on a Si backplane with a near-standard CMOS process and include the driving circuitry that delivers the appropriate voltages to the Al electrodes that define the pixels. There are also layers above the aluminium for planarization, reflection enhancement, and liquid-crystal (LC) alignment. Above the backplane lies the LC layer, followed by an anti-reflection coating, then a common transparent electrode of indium tin oxide (ITO), both on a sheet of glass. (The details of the electro-optical operation of the LCoS display is beyond the scope of this article, but see Reference 1.) All of this is inserted into a package for mechanical and electrical connection to the rest of the system (see Figure 2).

Figure 3 shows the architecture for a typical three-LCoS projection system. There are three major components to this system. First is the illumination system that generates white light, typically from a metal halide arc lamp. Next, the light is broken up into red, green, and blue bands, pre-polarized, after which the polarization beam splitters (PBSs) dump each into a separate color channel.

The way the LC manipulates polarization depends on the mode in which it is operating, as shown in Figure 4. On the left is shown a vertically-aligned nematic (VAN) mode. In the unpowered state, the LC molecules stand up and the retardation of the crystal is nearly zero. In this case, the polarization state is unchanged. In the powered state, the LC molecules are forced into the plane of the display, and the design is such that in this state the retardation is about 1/4 wave. This causes the polarization at the mirror to be circularly polarized. Upon reflection, the handedness of the circular state is reversed (just as a clock face is reversed when seen in a mirror). This has the effect that the outgoing polarization is rotated 90° with respect to the input

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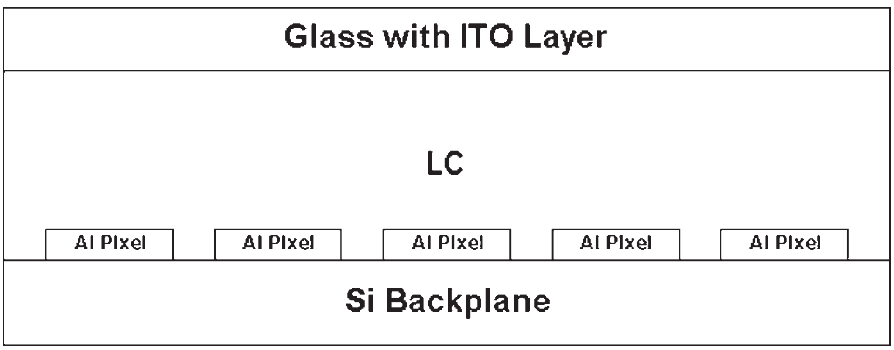

Figure 1. Schematic of the basic structure of an LCoS microdisplay.

Special Issue on:
Displays

Guest Editor
Gabriel Marcu, Apple Computer

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Is the CRT's obsolescence imminent?

In the 1970s, when a young engineer, fresh out of school, started work at a Toshiba CRT (cathode ray display tube) factory in Japan, his manager told him that he was making a big mistake. "This is a sunset industry," his manager said. "Soon, CRTs will be obsolete." Now, more than 30 years later, LCD, plasma, Digital Light Processing™, and their variants are eroding CRT markets at a surprising pace, and it appears that LCDs will dominate most high-volume application areas. So we find ourselves wondering: is that manager's prediction finally about to come true?

CRT vs. LCD

Unlike LCDs, CRTs can directly generate images in a variety of formats, and do so without digital image scaling and the problems that go with it. They also currently enjoy superiority over LCDs in the areas of cost, viewing angle, and smooth presentation of motion.

Chief among the reasons the CRT is more cost effective than LCDs are the CRT's ability to address millions of pixels sequentially with only three analog video signals, and the lower cost and longer lives of CRT production lines.

Mature progression

Mass production of television receivers following World War II established CRTs as mature display components. Advancements in the technology came more slowly after the introduction of color tubes in 1950s. Those tubes used a 'delta gun': three electron guns mounted in a triangular configuration in the neck of the CRT. The red, green, and blue guns emited electron beams, which were scanned over the screen by a deflection yoke. A sheet of steel inside the tube, mounted close to the screen, used parallax to make sure each beam only struck its corresponding colored phosphors.

In the early 1970s, guns shifted from the delta to the inline configuration, in which the three guns were side-by-side. This resulted in a reduction in the number of adjustments needed to align the red, green, and blue images with respect to one-another, and eventually allowed the shipment of pre-aligned tube-yoke combinations to receiver and monitor assembly factories.

The ability to systematically model electron behavior in the electric and magnetic fields of a color CRT has been the most powerful enabler of the development of the technology. Early modeling techniques were borrowed from early particle accelerator work in the 1950s and 1960s and, in 1975, a paper from Zenith articulated the principles of CRT electron gun optimization. By the early 1980s, computer-modeling tools had been developed—thus reducing the need for physical prototypes—and the pace of innovation quickened.

Around 1982-1983, RCA started production on the COTY (cost-optimized tube and yoke) gun. The COTY made a tremendous improvement in the tradeoff between deflection power and beam distortion and was quickly adopted by CRT manufactures the world over. In the late 1980s, the dynamic quadrupole yoke was introduced. This almost completely compensates for deflection defocusing of the beams from self-convergence yokes used with inline guns. Though it took nearly 10 years to perfect, it made 110° display tubes and, thus, thinner displays practical: it was the last great breakthrough in gun design.

The emergence of a market for high-resolution personal computer displays in the late 1980s, a sense of competition with LCDs, and the burgeoning market for HDTV receivers were the main forces driving improvements in not only guns and deflection yokes, but also in screens, magnetic shielding, and glass technologies. Then, in the early 1990s, TDK developed the RAC deflection yoke and tube system for Toshiba. RAC systems have rectangular-shaped CRT necks and yokes, which results in an impressive 30% reduction in deflection power. As with the COTY gun, RAC and RAC-like systems are becoming pervasive, having since been adopted by Matshita, Philips, LGE, and others.

To the future

Modern-day CRTs can inexpensively provide large, bright images with a large color gamut. Resolution has reached 0.125mm, new cathodes deliver brighter pictures with lower-cost circuitry, and bulbs have become wider and their depths shorter. Although those working in CRT research and development agree that there will not be any more big-budget projects on the scale seen in the past, innovation continues. A recent example is a set of technologies for television, known collectively as 'slim' CRTs, which are in pilot production. One is Philips' new 32" wide-screen RealFlat™ tube for HDTV, with a depth of only 35cm.

The CRT will be still be around for a very long time because of its low cost compared to other technologies. Perhaps, as that manager in the 1970s said, the CRT industry is a 'sunset industry': but it's taking a very long time for that sun to slip below the horizon.

The author wishes to acknowledge contributions to this article from: Roger Alig, Hsing-Yao Chen, Chris Curtin, Basab Dasgupta, Carlo Infante and Seyno Sluyterman.

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LCDs get up to TV speed

LCDs enabled the notebook computer application, have greatly reduced the weight and volume of monitors, and are in everything from PDAs to fish finders. Now, the technology stands poised to take on the biggest display market of all: television. However, TV requires much more than simply scaling existing LCD-monitor panels to wider (for 16:9 HDTV) and larger sizes. A number of TV requirements exceed the state of the art of today's monitors—such as brightness, contrast, color envelope, color temperature, and progressive scan—and require a re-engineering of the monitor solution. In particular, one fundamental deficiency of LCDs must be overcome before they can be widely applied to TV: LCDs respond too slowly for TV video applications.

Computer applications are very forgiving of slow pixel-response times. The same is even somewhat true for DVD movies. Compared with the typical LCD refresh rate of 60 frames per second, DVD movies are typically filmed at a slow 24 frames-per-second, resulting in moving objects being blurred in the original content.

Broadcast TV is another story. Each frame—or field in the case of interlacing—is captured in less than 1/60th or 1/50th of a second depending on the broadcast standard. The original moving component of the image is captured in sharper detail, and, in addition, must be rendered on the display screen at faster rates than movie frames. Response time is much more of an issue for television than for most other video sources, and it is particularly important for high definition TV (HDTV).

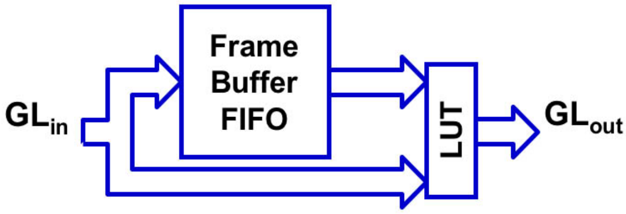

Figure 1. General block diagram of the RTC (response-time compensation) overdrive function.

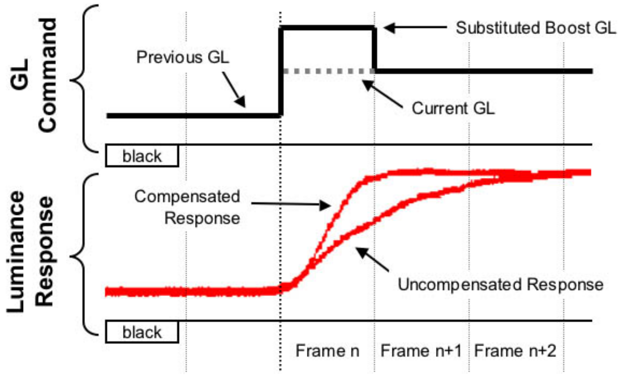

Figure 2. An example of RTC overdrive. A surrogate GL is substituted for the intended GL that causes the output to meet the intended luminance by the end of just one frame.

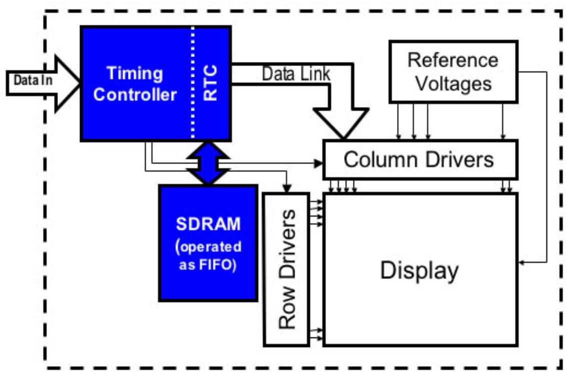

Figure 3. An example of RTC overdrive in the system. Highlighted is the added function of the timing controller in the LCD module. An external RAM is used as frame FIFO (first in, first out) memory.

Why optical response lags the voltage command

The light transmission through a liquid-crystal pixel is controlled directly and immediately by the orientation of the liquid-crystal molecules to the propagating light wave. But it takes time to move the molecules from one position to another, and this transition entails the response time that is characteristic of an LCD. The transition time between any two grey levels in an LCD depends on two factors: the net torque on the molecule, and the resistance to movement arising from material properties and geometries such as flow dynamics, cell thickness, and viscosity.

The net forcing torque on the LC molecule, i.e., the one that makes it move, is the momentary imbalance of two competing torques—the restoring torque that tries to pull the molecule back to its resting position and the exciting torque that is induced by the voltage applied to the LC which tries to align the molecule in its electric field. This field-induced torque varies with the square of the applied voltage, but the restoring torque is not field-dependent. In other words, the LCD optical rise- and fall-time mechanisms and rates are different. Depending on the direction of the transition, the purpose of the applied compensation is to either over- or underdrive the display. The mechanism to implement these strategies, however, is the same in both directions of compensation.

Theory of response-time compensation (RTC)

The basic theory of operation is simple and shown in Figure 1. The RTC block intercepts the digital video stream and compares the previous grey-level (GL) command to each pixel with the current grey-level command. It then chooses a predetermined alternative grey level from a look-up table (LUT). This alternate is applied by this mechanism for only one frame. In the next, a new comparison between previous and current grey level will take place. If the LUT's surrogate grey level is correct, it will have the effect of transitioning the transmission of the pixel from the previous to the current grey level in this one frame. Figure 2 illustrates the over-drive concept in terms of this grey-level signal. Because every combination of previous and current commands is accounted for in the LUT, both directions of compensation are provided. Figure 3 illustrates a typical RTC block as the last stage of the panel's timing-controller ASIC. This keeps the display panel and the LUT that characterizes it in the same module allowing the RTC LUT contents to be specific to the particular display characteristics.

How well does RTC work?

Success in forcing the LCD to reach the target brightness value in one frame depends, at least in part, on the quality of the LUT contents. The RTC-boost values are predetermined based on a particular frame interval and also on a particular temperature. A LUT of values pre-selected for 60Hz will not be optimal for 50- or 75Hz operation. And higher temperature results in faster transitions. Thus, tables calibrated at one temperature are not good for another. It is clear that RTC is the key enabling technology for helping LCD monitors make the transition into the consumer-television market. Equipped with RTC, LCD TVs have the required sharp, bold, moving images needed to

Continues on page 8.

Projection displays

A projection display consists of a projector and a screen, or—for the largest displays—multiple projectors tiled together on a single screen. The color characteristics of a projection display are determined primarily by those of the projector. The screen contributes to the image appearance by affecting brightness, viewing angle, and sharpness.[1]

The first color projectors consisted of three monochrome CRTs filtered to create three separate red, green, and blue images, each projected through its own lens. These images were recombined at the screen, resulting in a system that was difficult to align and images that were not very bright. Modern CRT systems produce higher-quality images, but have been replaced in most applications by projectors based on digital imaging technology.

A digital projector contains a digital imaging element such as a small liquid crystal display (LCD) or an array of micro-mirrors (such as the Digital Micro Display or DMD™) that modulate the light from a high-intensity bulb. Most digital projectors contain three imaging elements and a dichroic mirror that splits the white light from the bulb into its red, green, and blue components. These are recombined and displayed, simultaneously, through a single lens. The quality of the optics for the splitting and recombining strongly affects the image quality: color, uniformity, sharpness, and convergence.[2]

The smallest projectors use a single imaging element and a color wheel of filters, displaying the red, green, and blue images sequentially. The small DMD projectors based on the Digital Light Processing (DLP™) technology from Texas Instruments include a clear filter in the color wheel that is used to add white light to the brighter colors. This increases the brightness and contrast of the system, but only for a limited set of colors near white.[3]

In an LCD projector, the liquid-crystal panels act as light valves, modulating the amount of light displayed by varying the opacity of the pixel. Normally, light shines through the LCD. An LCoS (liquid crystal on single-crystal silicon) imaging element, however, combines the liquid-crystal light valve with a reflective silicon surface. Light is modulated by the liquid crystal and reflected out the lens.

In a DMD projector, each pixel is defined by a tiny, tiltable mirror. Light is directed either out of the lens, or into a black cavity, depending on the angle of the mirror. To vary the intensity, the mirrors are flickered to create a stream of light pulses.

Figure 1. Non-uniform brightness distribution typical of a digital projector. That the brightest area is near the bottom of the image, rather than in the center, is typical of projection optics with keystone correction.

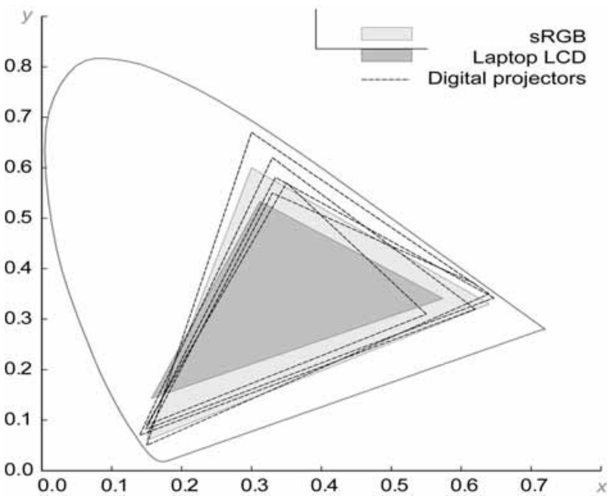

Figure 2. Chromaticity diagram comparing the gamuts of a five different digital projectors to the sRGB display gamut and that of a typical laptop LCD display.

Imaging properties

The imaging properties for a projector are its brightness, contrast, and resolution. Brightness is usually specified in ANSI lumens, which are measured by averaging nine readings sampled across a uniform white field. This value will be much lower than the maximum brightness, as projectors do not produce a uniformly-bright image, as shown in Figure 1.

Projection systems designed for rear projection are brightest in the center of the field, and high-end systems may fall off as little as 15% in the corners (less than a typical CRT display). Most projectors, however, create a pattern that is brightest at the center of the bottom edge. This is the result of keystone correction, where the lens is offset with respect to the imaging element. The result is a projection path whose bottom edge is nearly stationary with respect to distance from the lens. This makes it possible to set the projector on a table without clipping the bottom edge of the image. For small, commodity projectors, the brightness in the top corners may be 65% or less of the brightest point.

Contrast for projection displays is described as a ratio, such as 300:1, which represents the relative brightness of the brightest white and the darkest black projected. The advertised contrast numbers, which can exceed 1000:1, are often extreme, rather than typical values, and as such are not good predictors of image quality. "Black" on projection displays is usually a visible gray, caused by light leaking through the lens. Only CRT projectors can produce an invisibly dark black.

The native resolution for a digital projector is defined by its imaging element. Displaying other resolutions is implemented by electronic resampling the input image. The most common resolution is XGA (1024×768), especially for portable projectors. However, some high-end systems are providing UXGA (1600×1200) resolutions, and higher. A large digital cinema system has a resolution of 2048×1080.

Color properties

Color projectors are additive color systems, where the color at each pixel value is defined by the RGB primary colors and the transfer function that maps pixel to brightness values.

The primary colors for a projection system are defined by the bulb and filter colors. There is variation in both, as well as variation in the bulb due to aging. Even projectors of the same model can have visibly different color gamuts, although this can be minimized by carefully matching the red, green, and blue transfer functions. The primaries chosen for digital projectors are often visibly different than those for

Continues on page 8.

Colorimetric characterization of projection displays

In recent years, rapid advancements have been made in the area of projection display systems. Improved image quality—especially higher resolution and luminance—along with size and weight reduction have widened the areas of application to include areas such as cinema, home and public entertainment, advertising, simulation, and information display.

It is well known that different color imaging devices reproduce color differently. While this is quite obvious when comparing fundamentally different devices such as printers and monitors, it is also true for devices of exactly the same type. Even two projection displays of the same make and model will have different colorimetric characteristics: for example, due to variations in the characteristics of the lamp.

To achieve consistent reproduction of color it is therefore necessary to perform some sort of color correction for each individual projector. The theory and practice of color management, a concept well known in the graphic arts, provides a framework that allows for such corrections. Color consistency is achieved by mapping the color space of each individual device into a device-independent color space such as CIEXYZ.

Generally, an exact mapping does not exist, and therefore different analytical characterization models are employed to different devices to best approximate this mapping. This process of determining a suitable mapping function and optimizing its parameters for a given device is called colorimetric characterization.

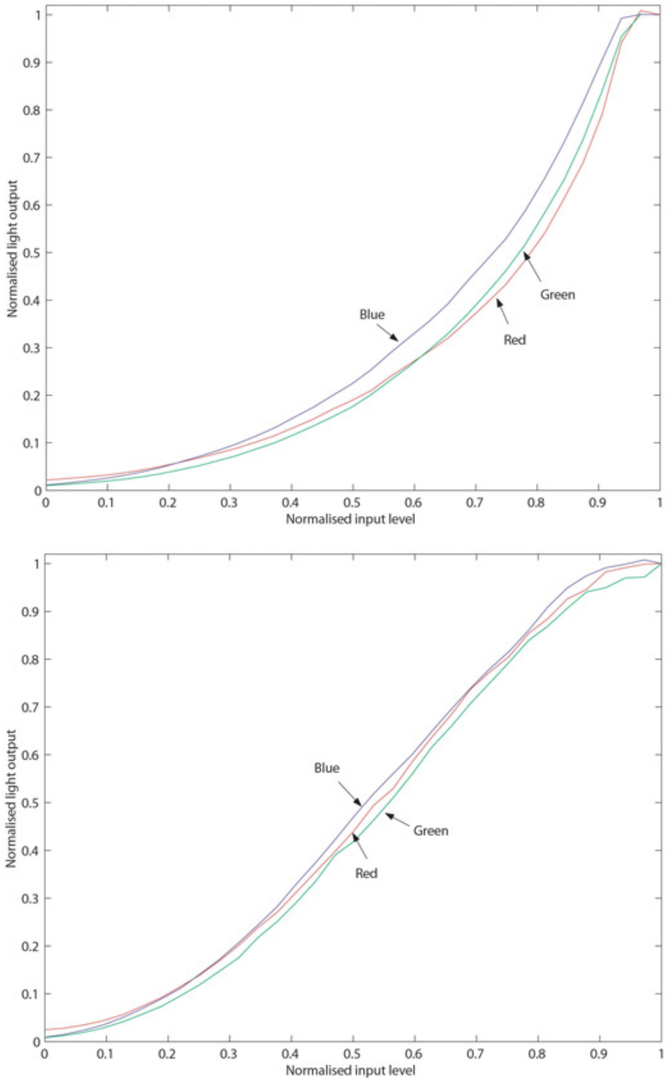

Figure 1. Output response of the primary colors as a function of the R, G, and B input levels for the LCD (top) and DLP projector (bottom).

The substantial increase in use of projection displays makes color management of different types of projectors an important issue. In order to achieve this, consistent and standardized methods of characterization should be established. The International Electrotechnical Commission (IEC) has made an effort to standardize the characterization of projection systems, but little progress has been made since the completion of a working draft in 1998.[1]

Display characterization models

For cathode-ray-tube (CRT) projectors it is common to assume that they can be described as an ideal additive RGB system, and to use a simple characterization model that predicts the displayed-color tristimulus values CIEXYZ from the device-input RGB using non-linear gamma calculations followed by a 3×3 matrix operation. This model is typically known as the gain-offset-gamma (GOG) model.[2]

In recent years. liquid crystal display (LCD) technology is increasingly replacing traditional CRT display technology, both for desktop monitors and projectors. The colorimetric characterization of these devices presents several difficulties compared to that of CRTs because of issues like high black level, inter-channel dependency, imperfect color-tracking characteristics, spatial non-uniformity,[3,4] dependency on background, and lack of temporal stability.[1,5] There have been relatively few reports of the successful colorimetric characterization of LCD projection displays.[4-6]

For Digital Light Projectors (DLP™) based on the Digital Micromirror Device (DMD™) technology, it is common to employ a transparent segment in addition to the red, green, and blue portions of the color wheel in order to increase the projector's brightness. This presents a challenge for colorimetric characterization; especially since the exact algorithm for adding the fourth white channel is generally not known.[4,5] Recently, Wyble and Zhang proposed an approach to solving this problem.[7]

Results

In our study[5] two projector systems were characterized, one based on LCD technology, the other on DLP technology. The LCD projector showed fairly good inter-channel independence, especially when accounting for the black level. The method proposed[1] for calculation of inter-channel dependency does not seem to be directly applicable to the tested DLP projector due to the non-filtering segment.

The two projectors showed power-function-like and S-shaped tone responses for the LCD and DLP projector, respectively (Figure 1). The intrinsic responses of the projectors are S-shaped for the former and linear for the latter. The actual responses therefore seem to be deliberately manufactured by internal processing.

The chromaticity changes of the primaries resulting from changes in the input signal were found to be significant. The relatively high black level is the dominant reason for these changes.

Measurements of 25 spots over the images revealed poor spatial luminance uniformity for both projectors. The intensity of the dimmest spot relative to the brightest was only about 20% for the DLP and 30% for the LCD projector. Somewhat unexpectedly, the LCD showed significantly better spatial color uniformity than the DLP projector.

Tests showed that both the intensity and the color of the background influenced the displayed color. A set of nine color patches, each

Continues on page 9.

Active-matrix liquid-crystal displays (AMLCD)

Active-matrix liquid-crystal displays (AMLCDs) have enjoyed rapid growth in the past decade. In the last few years, while the global high-tech industry has been in slow motion, huge investments have continued to pour into the manufacture of LCDs. It is now a US$50 billion business, and is still growing rapidly. Besides the established of these devices in notebook PCs and flat-panel monitors, emerging applications include cell phones, handheld devices and LCD TV. The process of replacing the CRT by AMLCD has begun in earnest and, leading the way, are amorphous silicon-based thin-film-transistor (TFT) LCDs.

Twisted-nematic (TN) LCDs

There are various liquid-crystal technologies involved in different LCD operations with different viewing-angle requirements. The three leading modes are twisted-nematic (TN), in-plane switching (IPS), and multi-domain vertical alignment (MVA). Most LCDs are still using the twisted nematic (TN) liquid crystal cell that was invented in the early 1970s. The 4-5μm-thick LC layer is sandwiched between transparent conductors on two glass plates. These each have an alignment layer, which causes the elongated LC molecules to twist by 90° from front to back plate. Perpendicular polarizers are attached outside the assembly.

Without an applied electric field, the linearly-polarized light transmitted through the first polarizer is rotated 90° by the TN cell and will be transmitted by the second polarizer. When an AC voltage of about 2-4V is applied across the LC cell, the molecules align along the electric field and the polarization direction is no longer rotated by the LC. As a result, the second polarizer blocks the light. This operation is called the normally-white mode. At intermediate voltage levels, a continuous grey scale can be achieved. The LC cell needs to be operated with an AC voltage without a DC component in order to prevent degradation of the LC-cell structure.

The best way to address the display pixels is through an active-matrix of TFT devices. This adds a switch at each TN-LCD pixel to control voltage independently and obtain the intended grey level. Since most TFT-LCDs are backlit, their luminance is proportional to the backlight intensity. Peak brightness of 150-400Cd/m^2 is typical. The white luminance is the sum of the red, green, and blue luminance components. The contrast ratio, which is defined as the ratio of maximum to minimum luminance, can exceed 500:1.

The transmission-voltage curves of TN cells vary significantly with viewing angles, especially at intermediate grey levels. This can be explained by the orientation of the LC molecules in the center of the cell, which is very different for positive and negative vertical viewing. A typical viewing cone for the TN LCD has a 90° horizontal- and just 45° vertical angle. For the typical single-person usage of most notebook and hand-held applications, this TN optical characteristic is sufficient. However, for high-end portables or monitors, people usually apply wide-viewing films (retardation films) onto the TN cell. Retardation films are attractive because they do not require any change in processing up to the final lamination of the polarizers. Retardation films compensate for the retardation in the LC layer and improve horizontal and, to a lesser degree, vertical viewing angle. The wide-viewing films can enlarge the viewing cone to up to 140° horizontal and 100° vertical. This technology can be found in Apple 15.2" and 17" PowerBooks and almost all 15" and 17" LCD monitors.

In-plane switching (IPS) LCDs

The best viewing angle is achieved in the IPS mode. Here, the electric field is applied parallel to the glass plates by applying a voltage between electrodes on the TFT array. The lateral electric field causes the LC molecules to rotate parallel to the plates and leads to a very wide viewing cone. The viewing angles can be extended to 170° both horizontally and vertical, with a very consistent grey-scale behavior and a minimal color shift. This is particularly important for professional uses of an LCD monitor. The response time has also been improved to be comparable to TN by employing an over-driving approach. Drawbacks are a generally a lower pixel aperture ratio to accommodate the multiple electrodes on the pixel. There are also some manufacturing yield challenges. All Apple Cinema Displays employ IPS technology.

Multi-domain vertical alignment (MVA) LCD

Another successful approach is to use the MVA mode, in which the LC molecules are aligned perpendicular to the glass plates in the absence of an electric field. The LC fluid in the MVA mode has a negative dielectric anisotropy. This means that when a voltage is applied between the transparent electrodes on the two plates, the molecules rotate to become parallel to the plates. In order to obtain a symmetrical viewing angle, the pixel is subdivided in domains, in which rotation starts with different initial tilts. Great efforts have been made to improve MVA, so much so that its viewing cone and angular color behavior are now fairly comparable to those in IPS. The mode also eliminates a rubbing process required for alignment in TN and IPS cells, resulting a simpler manufacturing process. The MVA mode is popular in desktop monitors and, as well as a wide viewing angle, has a high contrast ratio (up to 1000:1).

Conclusion

TFT LCDs have enjoyed tremendous growth recently as a result of image-quality improvements and large cost reductions. The image quality is now similar to that of CRTs, while power consumption is about 50% lower. After successful application in notebook panels and desktop monitors, the next big additional market for AMLCDs appears to be in cell phones, handheld devices and television. TFT LCDs of up to 57" and high-resolution displays with over 200 pixels per inch have been demonstrated and are now slated for production. Both IPS and MVA wide-viewing-angle technologies are fiercely battling for application to LCD TV. While IPS needs further improvement of its contrast ratio, MVA must reduce the angular dependence of its grey scale.

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High-resolution liquid-crystal displays: image quality and bandwidth requirements

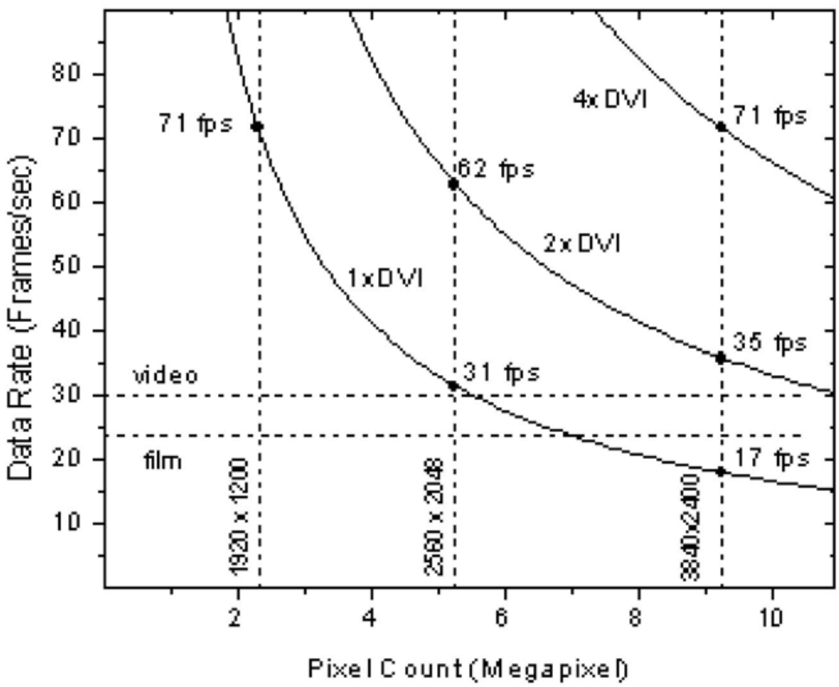

Figure 1. Data frame-rate limitations of DVI channels providing 165Mpixel/sec.

In the late 1990s, 200-300 pixels-per-inch (ppi) prototype liquid-crystal displays (LCDs) were produced. Viewed from approximately 17", a 200ppi screen provides 30 line pairs per degree of visual angle and matches the spatial resolution required for 20/20 visual acuity. Advances in liquid-crystal optical performance, pixel-array process, drive electronics, backlights, and manufacturing yields have combined to allow high-performance eye-matched large-area displays to enter the marketplace. High prices, combined with a general malaise in the information technology sector during 2000-2003, slowed the adoption of this technology. However, recent interest in flat-screen HDTV, coupled with price reductions, has renewed interest in the benefits of high-resolution LCDs for a broad range of applications. Improved image quality, equivalent to transparency film or high-quality print, has stimulated interest in projection and direct-view high-end display products for entertainment, medical, and computer applications.

Examples of high-end LCD monitor products include IBM (3840×2400, 22.2", 204ppi),[1,2] Apple (1920×1200, 23", 98ppi), Samsung (1920×1200, 24", 94ppi) and Sharp (2560×2048, 28", 116ppi). Human-factors studies have confirmed that improved task performance can be achieved with higher pixel-density displays.[3-5] The highest pixel density, 204ppi, is obtained with the 9.2-million-pixel IBM T221 display. This display uses the dual-domain in-plane-switching liquid-crystal mode to greatly reduce the dependence of image color and contrast on viewing angle within an 80° viewing cone.[6] The display has a built-in 10-bit-color look-up table (LUT) that can be used with color calibration and management software programs.[7] For medical applications, use of this LUT—combined with subpixel dithering techniques—have enabled extremely accurate luminance precision[8] for DICOM calibration. Compared to a monochrome multi-monitor configuration, a single-color T221 provides excellent value[9] and performance[10] for medical applications. For color applications, the 10-bit LUT allows much finer control of color and luminance than can be achieved with a standard 8-bit-graphics-card LUT.

The number of screen pixels and the screen refresh rate determine the data rate to the display. The high pixel count of large-area, high-resolution LCDs challenges the graphics card and application to provide this data. The IBM T221 contains a built-in frame buffer to decouple the screen refresh rate and input data rate. Although it is possible to drive well-designed LCDs at very-low screen refresh rates without flicker, screen refresh rates are typically fixed in the range 40-60 frames per second (fps). The IBM T221 achieves excellent static image quality at very-low full frame data rates, as low as 13fps, using any inexpensive digital graphics card with a single digital video interface (DVI) output and correct timing to support the 3840×2400 format. Good motion rendering with typical object or camera motions requires data rates of at least 24fps. Fast-moving objects or camera pans can require 60fps or higher. The IBM T221 supports 1-4 DVI input channels and can accept up to 48fps full-resolution video.

Formats beyond HD resolution for video present a bandwidth problem common to all displays and image capture devices. At a video frame rate of 30 fps, HD (1920×1080) format requires a data rate of 1.5Gb/s. There is a fundamental tradeoff between pixel count and data frame rate for a given channel bandwidth. This is illustrated in Figure 1, assuming noise-free graphics-card operation at the maximum DVI clock rate of 165MHz and with little or no blanking time. For each DVI clock period, one 24bit pixel is transmitted. Although there have been several recent digital video camera products announced with 4×HDTV resolution, most video data is limited to 1920×1080: well-handled by a single DVI channel.

However, digital-still-camera, computer-generated-graphics, medical-imaging and geographic-information systems often produce very large images. The display of these images can require rapid pan, zoom, and rotation without artifacts. This presents a challenge for both the software application and graphics card hardware acceleration. Most graphics card development is oriented toward acceleration of 3D effects, not 2D functionality. For computer generation of large moving images, parallel rendering by a cluster of computers is required.

LCD manufacturers have improved moving-image quality by improving the fundamental operation of the liquid-crystal light valve. Techniques include the use of faster switching liquid crystals, signal processing to speed up switching, and pulsed backlighting. If the screen refresh rate is not the same as the data frame rate, re-sampling artifacts will occur. Such artifacts appear as a motion discontinuity or judder at the temporal difference frequency. If this is near 8Hz or lower, it will be visible.

LCDs use data-polarity inversion to prevent chemical changes in the liquid-crystal cell and to suppress crosstalk and flicker effects. For many LCDs, the screen refresh rate is fixed at

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LCoS microdisplays for projection television

Continued from cover.

polarization.

On the right is shown a twisted-nematic (TN) mode, which operates somewhat differently. There are many different variations on this theme (as discussed in Reference 1). The unpowered state produces circular polarization at the mirror surface, and is somewhat similar to the powered state of the VAN, although in this mode the change in polarization is due to a complex combination of birefringence and optical activity. The powered state is likewise similar to the unpowered state of the VAN mode, although in this case, there is always a small amount of residual twist left: this is why the optical performance of the VAN mode is preferred.

Figure 2. Aurora Systems liquid-crystal-on-silicon (LCoS) packaged imagers displayed on a backplane wafer.

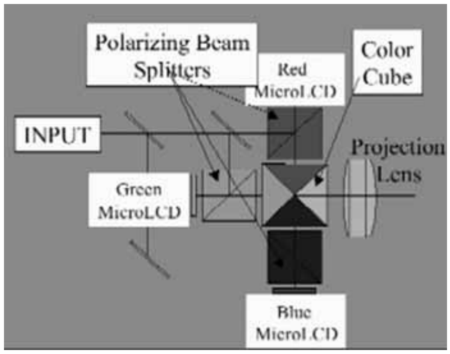

Figure 3. Typical three-color projection optical system for LCoS.

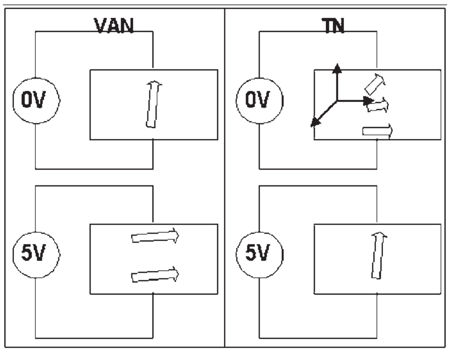

Figure 4. Representation of vertically-aligned nematic and twisted-nematic LC modes in the powered and unpowered states.

An LCoS display is a spatial, reflective light modulator that manipulates the polarization state of light on a pixel-by-pixel basis. When a pixel's reflection polarization state is rotated 90° with respect to its entry state, the PBS transmits the light through the projection system and onto the screen, producing a bright pixel. If the pixel reflects in the same polarization state in which it entered, the PBS will reflect the light back into the illumination system, producing a dark pixel on the projection screen.

LCoS projection products are at long last making it into the marketplace. Thompson/RCA had a short-lived product a couple of years back, but it was withdrawn before real production began. Philips now has the first real product line, called Cineos, in the stores. This uses a single-panel design, and produces color images through showing sequential red, green, and blue images during each frame. Toshiba was showing an LCoS-based TV at the Consumer Electronics Show this year. JVC have had a high-end digital cinema line of front-screen projection systems (D-ILA® or Digital Direct Drive Image Light Amplifier), using VAN technology, on the market for quite some time. They have also been demonstrating a consumer-level TV, also VAN-based, but on the Aurora backplane. Some of these products are expected to hit the shelves this year. Intel have announced their entry into the LCoS projection market, but they are being very tight-lipped about both technology and production schedules.

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Projection displays

Continued from page 4.

displays, creating substantial color shifts when colors designed on a display are projected. Figure 2 shows the primaries for five different digital projectors plotted together with the gamuts of an sRGB CRT and a laptop LCD display.

The native transfer function for a projector is defined by the imaging element. DMD elements pulse to encode the grayscale, making them naturally linear, whereas LCD elements are identical to liquid crystal displays. However, most projectors contain image-processing hardware that induces a transfer curve compatible with CRTs and video (a gamma curve).

Digital projectors include brightness and contrast controls like those on a desktop color display. Unfortunately, many projection systems used for presentation are installed without carefully adjusting the brightness and contrast to produce a smooth transfer function. This increases the often dramatic difference between the displayed colors on the speaker's laptop and the projected colors on the screen.

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LCDs get up to TV speed

Continued from page 3.

stand head-to-head and toe-to-toe with the entrenched alternatives on the TV-showroom floor.

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High-resolution liquid-crystal displays: image quality and bandwidth requirements

Continued from page 7.

60fps, pushing the residual low-contrast luminance flicker well outside the eye's window of visibility. For moving images, the least amount of flicker and crosstalk is achieved with input data rates exactly half the screen-refresh rate, with each frame presented in both polarities. To render fast object or camera motions, higher screen-refresh rates are required and can lead to flicker artifacts. There remains considerable disagreement among experts over required sampling rates to capture and render motion. The success of 24fps cinema, and the use of time expansion and contraction by cinematic artists for dramatic effect, suggests that—for many applications—lower rates will be sufficient.

The IBM T221 model DG5 has a screen refresh rate of 48fps, ideal for input source data at 24 or 48fps and compatible with both motion-vector interpolation and fade filtering schemes designed to reduce apparent judder.[11] The DG5 is capable of latching at different screen-refresh and input-data rates. When multiple DVI channels are used to render full-screen moving images, it is necessary to synchronize the DVI channels to avoid tearing artifacts.

To address bandwidth constraints, IBM Research is developing task-dependent hardware solutions. For multi-monitor environments with predominantly static imagery, a new VESA (Video Electronics Standards Association) digital packet video link (DVPL)[12] protocol standard has been established. DPVL takes advantage of new developments in 'intelligent' digital display hardware to allow selective screen refresh to lower data rates within a digital communications architecture. Some tasks, such as surveillance, are compatible with new sampling and compression techniques that can be combined to reduce transmission bandwidth requirements. IBM, under support of the US Army, and in collaboration with NASA and the US Navy, recently demonstrated new capabilities in this area[13,14] using digital, modular components for image conversion, compression, and transmission.

A net-centric architecture for communicating video data to displays is needed to accommodate the potential for eye-matched large-area display monitors. The need for this new architecture will become increasingly apparent as more applications emerge to take advantage of the opportunities to displace older display technologies, such as film and printing, with high-resolution flat-panel displays.

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Colorimetric characterization of projection displays

Continued from page 5.

displayed on the same set of backgrounds, gave a significant average DeltaE color difference of 4.83 for the LCD, and a more moderate difference of 2.94 for the DLP projector.

The characterizations showed that, with minor modifications to account for the black level, a conventional display model may be employed for the LCD projector for color management, giving an accuracy that is acceptable for most applications. An average color difference of 3.66 between prediction and measurement was found for a set of 20 random colors.

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Plasma display (PDP) as next-generation TV

Continued from page 12.

The CRT has a nonlinear light-intensity response to input digital values while the light-intensity curve of the PDP is close to linear within the normal operating range. Thus, in order to generate images on the PDP equivalent to those on the CRT, the input digital values must be made or modified for the PDP. This process is often called inverse gamma correction. When applied without any special conversion, the number of displayable grey levels in dark areas is considerably reduced. Figure 3 shows an example of inverse gamma correction. A straight line on the left side represents PDP luminance before this process has taken place: the smooth curve shows the desired luminance levels. Staircase-shaped lines represent the luminance levels after the inverse gamma correction. This result in a loss of detail in the dark scenes that frequently appear in movies.

To improve this situation, error diffusion and dithering have been widely used for inverse gamma correction. In the error-diffusion-based technique, the difference between the ideal and actual grey levels to be displayed on the PDP is taken as an error. This is propagated to the neighboring pixels after being multiplied by predetermined weights. With dithering-based techniques, input grey levels are converted into floating-point numbers according to the desired gamma value. The fractional part is thresholded by comparing it with the contents of a predetermined dithering mask. The thresholded value is then added to the integer part. The resulting grey level is displayed on the PDP. When error diffusion or dithering are used, the average grey level can be closely matched to the desired level. However, the difference in light intensity between two consecutive grey levels ranging from 0 to 30 is much greater than the contrast threshold of the human visual system. Thus, minor pixels would be perceived as isolated dots.

Several methods have been proposed to improve the image quality in dark areas. Generally, multiple sustain pulses are used for input level 1. Recently, single sustain pulses or light-emission by reset and addressing period have been proposed to represent it instead. This would, to a certain extent, reduce the difference in light intensitiy of two consecutive levels. An alternative approach is to modify the error diffusion technique to yield a homogeneous distribution of the minor pixels. In order to reduce undesirable regular patterns due to the dithering mask, the use multiple masks has been proposed.

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Plasma display (PDP) as next-generation TV

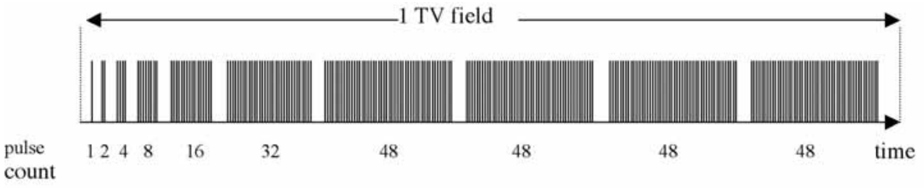
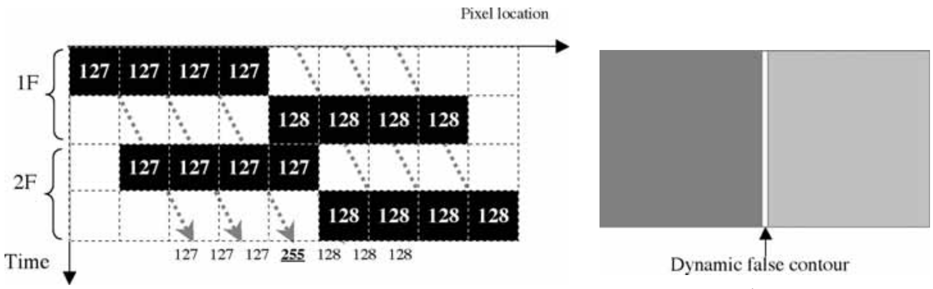


Figure 1. Example of a subfield pattern.



a b

Figures 2(a) and 2(b). Example of a dynamic false contour.

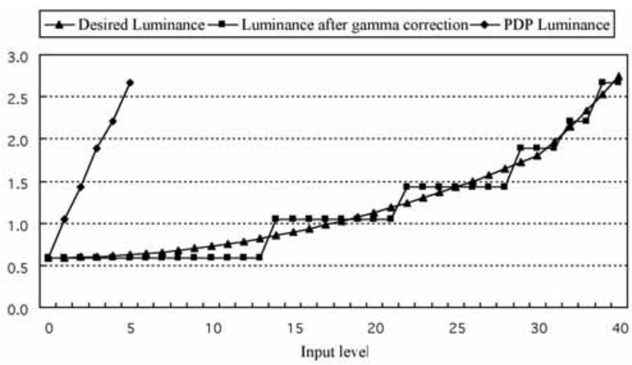


Figure 3. Example of inverse gamma correction.

Which display technology will dominate the flat-panel TV markets in future? That has been a question on the minds of those working in both the LCD and PDP industries, as well as consumers who plan to replace their old CRT-based TVs with a new flat digital HDTV. Both LCD and PDP have been competing for flat-panel-TV market share. A few years ago, the largest PDP on the market was only 42". But—at Cebit 2004 in—Hanover—80" PDP TV and 57" LCD TV were introduced. When"they go to shop for a flat TV, consumers examine price, image quality, power consumption, and brightness etc.. Those working with PDPs have been working hard to improve every aspect of these quality factors to compete against their LCD competition. In this article, we will consider the image-quality issues that are unique to the plasma display.

PDP represents grey scales through the pulse-count modulation technique. A TV field, 16.6ms in the case of 60Hz, is divided into a set of subfields (Figure 1 shows an example with 10). Each subfield consists of addressing-period and sustaining pulses. For example, grey-level 12 is displayed by turning on subfields 4 and 8. This is suitable for representing grey levels of a still image but causes problems for moving pictures. This is because, when an object moves, the human eye follows the motion. The brightness perceived by human vision system is determined by integrating the light emission over time in the direction of motion. Thus, when light emission periods of the grey levels for two consecutive frames are far apart, a false contour would appear. This is known as the dynamic false-contour problem.

Figure 2 shows an example of dynamic false contour. In Figure 2(a), horizontal location represents pixel position. The four pixels on the left have grey-level 127 and the four on the right have 128. The image is moved to right one pixel per TV frame. Arrows in Figure 2(a) represent the direction of integration. Figure 2(b) shows the image as perceived through the human vision system. Various techniques have been proposed to alleviate the problem of dynamic false contours. These include the optimization of the subfield pattern, the addition of equalizing pulses, the compression of light-emission time, and error diffusion. In this popular latter method, pixels or areas in motion are estimated first. Their grey levels are modified to avoid the dynamic false contour. Differences in grey levels are then defined as errors and diffused to the neighboring pixels to be processed.

Continues on page 10.

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