Digital Image Displays
Resolution, Brightness, Grayscale

Michael Flynn
mikef@rad.hfh.edu

A 1 Fluoroscopic/Angiographic systems
New Angio / Fluoro systems are now all sold with LCD displays for in room use.

A 2 QC image workstation
• Radiographers/technologists examine and approve the quality of each radiographic image, adjusting display factors if necessary.
• The QC station SHOULD be capable of displaying images with comparable quality to that used for diagnostic interpretation.
A.3 HFHS Tech stations
Delivery of images to the archive and RIS exam completion is done at technologist's workstations.

A.4 Radiologists Workspace
Two person workspace for teaching and consultations. Full width keyboard bench provides surface for both persons.

A.5 HFHS ultrasound module
Ultrasound workstations utilizing 1600 x 1200 color monitors.

A.6 Radiology Conference Room
40" LCD Monitors with DICOM calibrated grayscale and matched luminance range.
A.7 Radiology Conference Room - Alternatives

- Multi-input computer projection
- Computer, Film Camera, Slides, VHS, DVD

Ceiling mounted DICOM calibrated LCD (DVI) projectors

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A.8 HFHS Clinic stations

Clinical workstations
- Enterprise desktop replacement
- 1550 single 1mp color LCD stations

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A.9 HFHS Clinic stations

Clinical workstations
- 25 dual 1mp color LCD stations
- Surgery and selected Clinics

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A.10 HFHS Clinic stations

Specialized wall mounts with an overhead computer shelf in areas where space was limited

Main Campus ER
**B. LCD principles**

### Liquid Crystal Displays

**Principles of Operation**

- Liquid crystal display (LCD) devices have quickly replaced CRT devices as wide viewing angle designs have become available at modest cost.
- An understanding of the LCD principles of operations is helpful when selecting devices for use by different users in the medical center.

**B.1 Electro-optical Effect**

When LC molecules contact a grooved surface, they align parallel to the grooves. The director is altered by external electric field. When the director is twisted, light polarization also twists.

**B.2 Light Modulation With Polarizer**

With polarizer filters, the LC electro-optical effect defines light transmission as a function of applied cell voltage.

<table>
<thead>
<tr>
<th>Voltage (V)</th>
<th>Transmission (T)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>NB</td>
</tr>
<tr>
<td>Vth</td>
<td>NW</td>
</tr>
</tbody>
</table>

For normally black (NB with aligned polarizers), there is no transmission when voltage is applied.

**B.3 Elements of a TN LC Cell**

- Bottom substrate
- 90° twist
- Alignment layer
- Transparent electrodes
- Spacers
- Top substrate
- Polarizing Filter
- Backlight
- Transparent electrodes
8.4 Brightness by Backlight

- Multiple-phosphor lamps, reflector, diffuser.
- Behind panel (brighter) or on edge (uniformity).
- HCFT (hot cathode fluorescent tube): bright, 10,000 h life.
- CCFT (cold cathode fluorescent tube): 20,000 h life.
- New tube designs provide even longer life and adjustment of color temperature (multi-tube designs).

8.5 Brightness and Light Transmission

Power efficiency and brightness are related to optical performance of several layers.

8.6 Active Matrix Design

All pixels in a row are changed in sequence. No flicker even at modest refresh rates.
- a-Si TFTs:
  - good switching performance.
  - low leakage in OFF state.
- Aperture ratio:
  - Typically 50%
  - 80% (Sharp) high luminance.
- Challenges:
  - scan lines resistance (lag).
  - photo-conductivity.

8.7 Off axis contrast ratio

- The ratio of the maximum luminance to the minimum luminance is known as the contrast ratio.
- Contrast ratio is measured in the absence of ambient light.
- For LCD systems, the contrast ratio can be severely degraded in relation to viewing angle.
B.8 The TN Viewing Angle Problem

Due to the high anisotropy of light modulation:
- The effective cell gap (ON/OFF state) changes.
- The effective LC orientation differs for intermediate gray-level.

Solutions:
- Compensation foils
- Multiple sub-pixel domains (m)
- In-plane switching (IPS, mIPS)
- Vertical alignment (VA, mVA)

B.9 In Plane Switching (IPS)

Advantage: High contrast (excellent black).
Disadvantages: Low aperture ratio -> reduced brightness. Relatively high power slow response time.

For in-plane switching (IPS) designs, the rubbing directions are the same on the top and bottom of the cell. When an electric field is applied, the directors remain in plane producing improved viewing angle response.

B.10 Vertical Alignment (VA)

Vertically Aligned LCD
- LC alignment is from a protrusion producing directors that are perpendicular to the display surface. No rubbing processes are employed.
- The sub-pixel is divided into several regions in which the crystals are free to move, independently of their neighbors, in opposite directions (mVA).
- Wide horizontal and vertical viewing angle.
- Excellent low luminance response (deep black).
- Switching times are ~1/2 that of IPS designs producing improved cine display.

B.11 Multi-domain Cells

- 2- and 4-domain designs demonstrated, 8-domain designs simulated.
- The domain alignment is fabricated using:
  - differential rubbing treatments and photolithographic steps.
  - Patterned alignments with differential UV light exposure.
- Challenges:
  - domain stability (polymer stabilization)
  - more fabrication steps and cost

Emission angles can be distributed by using multiple domains with different orientations for each of the sub-pixels structures.
B.12 Macro Recording of LCD pixel structure

Leitz 24mm Summar
Ernst Leitz, Wetzlar (Germany)
Max aperture f2.0
Nikon PV4 bellows
Fuji S1 digital camera, ASA 1600

B.13 Dell 2000FP - 2MP

TN + Film
Macro photographs recorded with varying luminance.
Contrast/Brightness adjusted for similar appearance.

B.14 NDS Nova (iDtech panel) - 3MP

IPS - dual domain
Macro photographs recorded with varying luminance.
Contrast/Brightness adjusted for similar appearance.

B.15 Totoku ME201L (Sharp panel) - 2MP

VA - dual domain
Macro photographs recorded with varying luminance.
Contrast/Brightness adjusted for similar appearance.
B.16 SHARP T2020 - 2MP

VA - dual domain
Macro photographs recorded with varying luminance. Contrast/Brightness adjusted for similar appearance.

B.17 Digital Display Controllers

- In 1999, an industry Digital Display Working Group defined specifications for digital display connection.
- The DVI specifications is now the most common interface for graphic cards and monitors.
- Silicon Image’s PanelLink technology for Transition Minimized Differential Signaling (TMDS) provides the technical basis for the interface.

C. Frequently Asked Questions

FAQ
1. Equivalent contrast?
2. Grayscale calibration
3. Maximum Luminance?
4. Pixel Size (Distance)?
5. Field of View?
6. 8 bits?
7. Viewing angle?

C.1 Equivalent Grayscale Appearance?

How can display devices be configured so that the grayscale contrast of an image will appear the same on all devices?
1. Luminance ratio:
   LR = L'_{max}/L_{min} should be the same
2. Luminance response:
   Luminance vs P value should be the same.
C. 1a. Adapted Observer Performance

Observer performance is best when the visual system is adapted to the average scene luminance.

C. 1b. Luminance Range: Retinal response

The luminance response of photoreceptors in the eye is shown. The graph illustrates the relative photoreceptor response (P) versus luminance (L) for different adaptation levels:
- Low average luminance
- Medium average luminance
- High average luminance

C. 1c. Fixed versus variable adaptation

Contrast threshold for varied visual adaptation (Flynn 1999b). The contrast threshold, \( \Delta L/L \), for a just noticeable difference (JND) depends on whether the observer has fixed (B) or varied (A) adaptation to the light and dark regions of an overall scene.

C. 1d. Effect of \( L_{max}/L_{min} \)

- Digital radiographs should be displayed using over a luminance range of 250-350:1.
- Images prepared for range of 250 that are display on a monitor with large range will have poorly perceived contrast in dark regions.

PACS: ERGONOMIC CONSIDERATIONS
### C.1. LR for LCD monitors

- For CRT monitors, LR is set by adjusting brightness (Lmin) and contrast (Lmax).
- For LCD devices, only the backlight intensity can be adjusted.
- For LCD devices:
  - Lmin is set by adjusting the backlight brightness (current control).
  - Lmax is set as a part of the grayscale calibration (starting LUT value).

### C.2. Grayscale calibration

How can the luminance response of monitors with commercial graphic cards be calibrated to the DICOM Gray Scale Display Function (GSDF)?

1. Measure the gray palette
2. Generate a look up table (LUT)
3. Install the LUT in the Microsoft graphic driver.

### C.2.a LCD uncalibrated luminance response

The uncalibrated luminance response of an LCD panel typically has an irregular shape.

An increasing palette of luminance generated by sequentially incrementing R, G, and B values.

### C.2.b Luminance measurements

Calibration requires precise measurement of luminance for all gray values in the palette.

- 4 min for 256
- 12 min for 766
- 30 min for 1786
C.2.c DL/L for 766 palette sequence

The relative light change between sequential palette entries varies discontinuously.

C.2.d Calibration LUT

- Define the exact luminance for 256 luminance values that follow the DICOM 3.14 standard between a designated Lmin and Lmax.
- Adjust for ambient luminance by subtracting a specified value for Lamb.
- From the measured palette, select those RGB entries that most closely match the desired values.

C.2.e Grayscale calibration for enterprise systems

- Calibration look-up tables were generated for a set of Dell 1905FP monitors and found to be similar.
- A single generic LUT was identified for installation in 1000 workstations deployed for ePACS use.

- All ePACS stations have program shortcuts to display a test pattern and change LUTs.
- The DICOM LUT is reinstalled at every login.

C.3 Maximum brightness

What should the maximum brightness be?

1. This depends on the room lighting and ambient luminance of the monitor.
2. Lmin should be 5 times Lamb.
3. Lmax is then Lmin time LR.
C.3.a Effect of Lamb

Contrast reduction from diffuse added luminance

![Graph showing contrast reduction from diffuse added luminance.]

DICOM

D. LCD reflection

- LCD monitors have a complex reflection distribution
- Excellent performance can be obtained if light sources are located at more than 45 degrees from the surface normal

HFHS:
- Radiology: Lmax = 500, LR = 350, Lmin = 1.4 cd/m²
- Enterprise: Lmax = 250, LR = 350, Lmin = 0.7 cd/m²

C.4 Pixel Size

What should the pixel size of a medical monitor be?
1. This depends on the viewing distance, so this should be specified first.
2. For the specified viewing distance, the pixel size should be just small enough that the pixel structure is not visible.

C.4.a HVS: Retinal anatomy

The retina of the human eye contains a network of rods and cones interconnected by neural cells.
Particularly thin cones (2 μm) are densely packed in the central 50 microns of the fovea centralis. They provide high detail color response.

At 60 cm, 1 degree corresponds to a 1 cm field of view. This area is focused on a 288 micron region of the retina, the fovea centralis.

A variety of test patterns are used to assess visual acuity. Clinical measures are done typically with a Snellen eye chart. Much psycho-visual research has been done using sinusoidally modulated test targets.

Contrast sensitivity is the inverse of contrast threshold: $C_s = 1/C_t$

- At 60 cm viewing distance (0.33 m), 100 cd/m² luminance, square wave pattern, Cf = Lmax/√2:
  - ~0.5 c/mm
  - ~2.5 c/mm
  - 10% max

The pixel size of a display system that matches the resolving power of the human eye depends on the observation distance. The visual spatial frequency limit and associated pixel size can be defined as that for which $C_s = 10\%$ of maximum.

<table>
<thead>
<tr>
<th>Distance</th>
<th>Frequency</th>
<th>Pixel Size</th>
</tr>
</thead>
<tbody>
<tr>
<td>Close inspection</td>
<td>5 cycles/mm</td>
<td>0.100 mm/pixel</td>
</tr>
<tr>
<td>(0.33 m)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Normal viewing</td>
<td>2.5 cycles/mm</td>
<td>0.200 mm/pixel</td>
</tr>
<tr>
<td>(0.66 m)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Consultation view</td>
<td>1.7 cycles/mm</td>
<td>0.300 mm/pixel</td>
</tr>
<tr>
<td>(1.00 m)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Conference room</td>
<td>0.5 cycles/mm</td>
<td>1.000 mm/pixel</td>
</tr>
<tr>
<td>(3.00 m)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Note: idTech 3MP panel, 0.207 mm/pixel
C.5 Field of View

How large should the displayed area of a monitor be?
1. This also depends on the viewing distance.
2. For the specified viewing distance the diagonal dimension should be about 80% of the viewing distance.
3. For this size, all regions of the image are focused on regions of the retina with high rod density.

C.5.a Field of View

- 21 inch (diagonal) monitors with a field of 32 x 42 cm have provide an effective viewing field for digital radiographs at a normal distance (2/3 m).

C.5.b Pixel array and Megapixels

- The pixel size needed for visualizing full detail and the field of view dictate the pixel array size and the total number of pixels.

<table>
<thead>
<tr>
<th>Distance</th>
<th>Pixel size (mm)</th>
<th>32 x 42 cm array size</th>
<th>MegaPixels</th>
</tr>
</thead>
<tbody>
<tr>
<td>Close (0.33 m)</td>
<td>0.100 mm</td>
<td>3200 x 4200</td>
<td>13.4</td>
</tr>
<tr>
<td>Normal (0.66 m)</td>
<td>0.200 mm</td>
<td>1600 x 2100</td>
<td>3.4</td>
</tr>
</tbody>
</table>

- idtech 3 MP panel
  - 207 mm pixels / 20.8 inch (3.1 megapixels)

C.5.c Viewing distance and image zoom

- Use of image zoom features is ergonomically better than leaning forward for close inspection.
- Split deck tables with a broad front deck usefully prohibit close inspection with 3 MP monitors.
C.5.a DR interpretation

During interpretation, all regions of the recorded radiograph should be viewed with a 1 -> 1 alignment of image pixel values to display pixels.

C.5.b Regional zoom

- Zoom levels of 1 -> 2 and 1 -> 4 are needed to map detail at the detector pixel level to the region where visual contrast sensitivity is maximized.
- High zoom levels are of particular importance for direct DR detectors with extended MTF performance.

C.5.c Minification

- Minification of 2 -> 1 can also have value by increasing the frequency of diffuse structures and improving their contrast sensitivity.
- Such minification is commonly used for mammography and chest radiography.

C.6 256 gray levels

Is an 8 bit (256) grayscale sufficient?
1. It better be.
2. The large majority of systems use standard graphic calls with 256 level gray scales.
3. Specialized CRT graphic cards provide 10-12 bit gray levels.
4. However, for LCD systems the DVI interface constrains the RGB graphic size.
5. No studies have indicated that 8 bit graphic control effects diagnostic performance.
6. However, artifacts can be illustrated using test patterns with very gradual gray ramps.
C.7 Viewing angle

Do the viewing angle characteristics of LCD monitors cause problems?

1. Yes.
2. Manufacturers data on viewing angle can be misleading.
3. Recent studies have suggested how viewing angle can be specified for angles of acceptable contrast, however this is not presently provided by medical monitor suppliers.
4. Visual assessment using a contrast transfer test pattern are very useful.
5. It is important to assess contrast and brightness degradation in diagonal as well as hor/vert directions.

Questions