Characteristics and Performance Evaluation of LCDs used for Medical Image Display

Kenneth A. Fetterly, Ph.D.
Mayo Clinic, Rochester, MN

AAPM 2007

Outline

I. Resources
II. Technology overview
III. Evaluation tools
IV. Fundamental characteristics
V. Matching the display to the task
VI. Assessing and maintaining quality

What's not included

Cathode ray tube monitors
LCD with analog driver cards
Mammography specific requirements
QC procedures vendor provided

Along the way…

"Medical Imaging Grade" (MIG) Displays
Professional Displays
Consumer Displays
Color and Grayscale LCDs

Along the way…

- Assessment Methods
  - Quantitative
    - Photometer
    - Colorimeter
    - Scientific CCD Camera
  - Qualitative
    - Test Patterns
    - Trained Eye

I. Resources

- AAPM TG18: *Assessment of Display Performance for Medical Imaging Systems* (Online Report no. 03)
- NEMA DICOM, Part 14: *Grayscale Standard Display Function*
- VESA: *Flat Panel Display Measurements*
- DIN V 6868-57: *Image Quality Assurance in X-Ray Diagnostics, Acceptance Testing for Image Display Devices.*
- Peer review journals

II. LCD Technology: Optical Stack

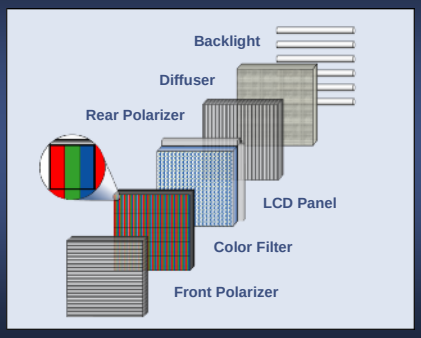


Image provided by J. Kofler, Ph.D.

Optical Theory

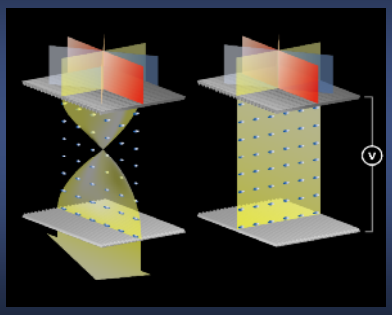


Image provided by J. Kofler, Ph.D.

Element Structure

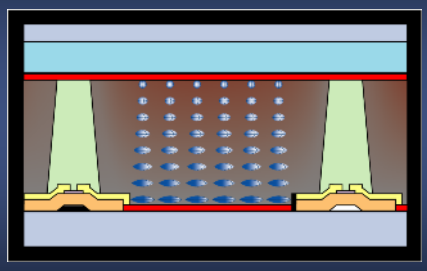
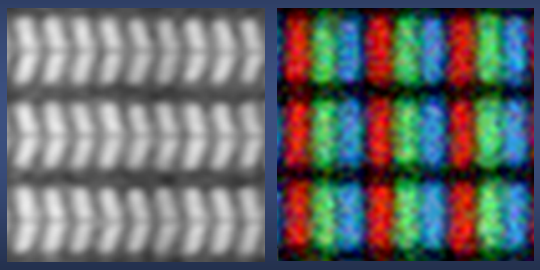


Image provided by J. Kofler, Ph.D.

LCD Technology Types

- Twisted Nemic (TN)
- Parallel Vertical Alignment (PVA)
  - Super PVA (S-PVA)
- In-plane Switching (IPS)
  - Super IPS (S-IPS)
  - Horizontal IPS (H-IPS)
  - Dual-domain IPS (DD-IPS)

Pixel Sub-Elements



Photos provided by Ehsan Samei, Ph.D.

III. Evaluation Tools

- Procedures
  - AAPM TG18
  - Vendor provided
  - Site specific
- Test Patterns
- Calibration SW
  - Vendor
  - 3rd party
- Photometer
  - Luminance
- Colorimeter
  - Color and luminance
- CCD Camera
  - 2D Photometer

Display Luminance

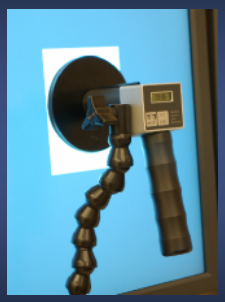
- Definition
  - Density of luminous intensity emitted by a light source in any particular direction
  - Light output, or brightness
- Units
  - Candela per square meter (cd/m^2)
  - Sometimes referred to as a "nit"

Photometer

- Measures luminance
  - Candela per square meter (cd/m^2)
- Practical range
  - 0.1 to 1000 cd/m^2 (5%)
- Narrow acceptance angle
  - 1 to 5 degrees

Photometer

Measures luminance
Units- cd/m^2



Colorimetry

International Commission on Illumination (CIE)

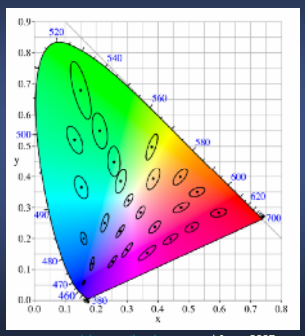
CIE 1931 (x, y, z)
- Used for display specification

CIE 1976 (u', v')
- Useful for color matching and quality control

$$u' = \frac{4x}{12y - 2x + 3} \qquad v' = \frac{9y}{12y - 2x + 3}$$

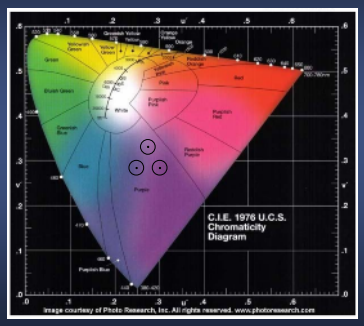
Color Temperature (K)

1931 CIE Chromaticity Diagram



www.vision.ee.ethz.ch, accessed June, 2007.

1976 CIE Chromaticity Diagram



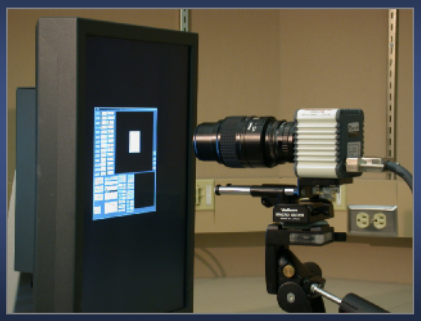
Photometers and Colorimeters

CCD Camera

Hamamatsu Orca ER

- Linear response, 12 bit Grayscale
- Matrix 1344x1024
- Peltier cooled to 20° C below ambient
- RMS noise: 8 electrons
- Dynamic Range 2250:1
- C-mount lenses
  - Nikon 180 mm, Fujitsu 4 mm (wide FOV)
- Manual pixel value to luminance calibration

CCD Camera



CCD Camera

- Acts as a 2D photometer
  - Requires calibration
- Used to measure
  - Luminance response
  - Resolution
  - Noise
  - Viewing angle effects

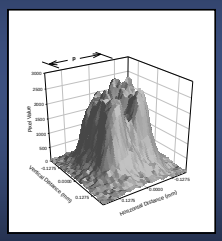
IV. Fundamental Characteristics

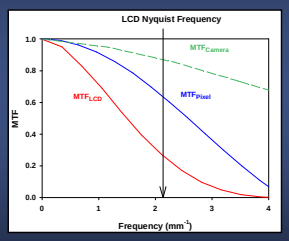
- Resolution
- Noise
- Dead Pixels and Artifacts
- Luminance properties
- Ambient light reflection
- Viewing angle
- Color tone
- HVS perception

Resolution: Pixel Matrix

	Matrix Size	Pixel Size (mm)	Nyquist Limit (mm^{-1})
2 MP	1600 x 1200	0.270	1.9
3 MP	2048 x 1536	0.210	2.4
5 MP	2560 x 2048	0.160	3.1

Resolution: Optical Blur



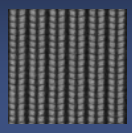


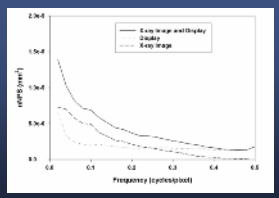
Visual Noise

- Fundamental difference in quality of LCDs.
- Can affect diagnostic performance for subtle findings.
- Not all displays provided by medical display manufacturers are good, not all consumer or professional displays are bad.

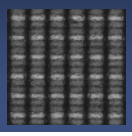
Visual Noise

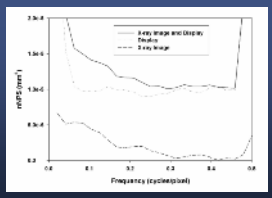
Low Visual Noise





High Visual Noise

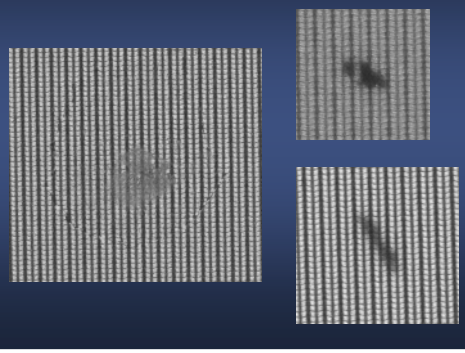




Dead Pixels and Artifacts

- Size and number
  - Whole or partial pixels
  - Dust and other contamination
  - MIG displays have specifications
- Location
  - Location in display influences importance

Dead Pixels and Artifacts



Luminance Properties

The luminance luminance vs. digital driving level response function of LCDs is highly variable.

Consistent presentation of images requires calibration to a standard based on the contrast response of the human visual system (HVS).

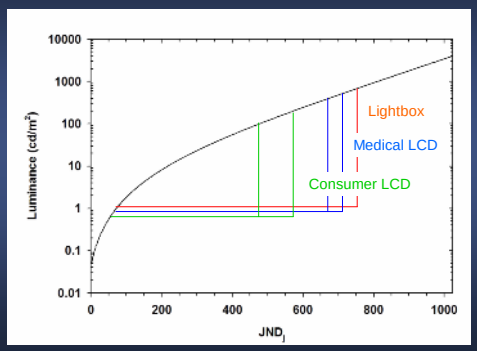
Grayscale Calibration

DICOM Part 14 adopted the Barten model of the HVS response to luminance contrast as the *Grayscale Standard Display Function* (GSDF).

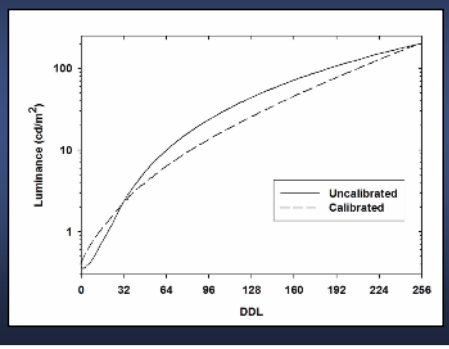
Based on *Just Noticeable Difference* (JND) index.

- For a given background luminance, specifies the change is luminance that is required for perception of a spatially varying sine wave.

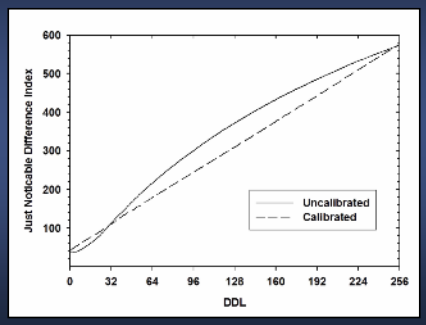
Barten Model



Luminance vs. DDL



JND Index vs. DDL



Luminance Properties

	Lum (cd/m^2) Minimum *Maximum*	JNDs Total *per DDL*
Medical Imaging	0.5 to 1.0 *400 to 600*	600 to 650 *2.3 to 2.6*
Consumer	0.5 to 1.0 *100 to 200*	400 to 500 *1.6 to 2.0*

Calibrating to the GSDF

Use a look up table (LUT) to map input DDL (p-value) to desired luminance.

Display systems are 8 bit.

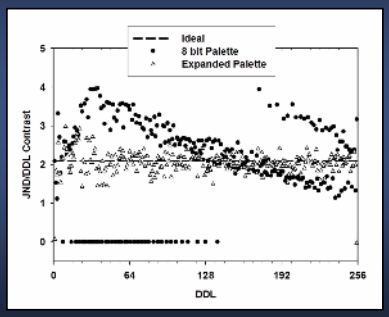
- 256 shades of gray
- 8 bit LUT would result in loss of grayscale detail

Spatial Dithering

Each LCD pixel has 3 subpixels.

- Can be used to create intermediate luminance values.
- Results in (256 x 3) – 2 = 766 gray levels for grayscale display
- Potentially more unique gray levels for color displays because colors are in different proportion.

JND/DDL vs. DDL



TG-18 QC Test Pattern

Is the grayscale ramp continuous?

Is "**QUALITY CONTROL**" equally visible?

Influence of Ambient Light

Reflection

- Function of the "optical stack," including protective panels, etc.
- Diffuse: adds to display luminance
- Specular: creates high luminance artifact

HVS Adaptation

- Eye adapts to environment, not just display
- "Disability glare" model may be useful

Coefficient of Diffuse Reflection

Surface	Diffuse Reflection* (cd/m² per lux)	Reflected Luminance (cd/m²) Reading Room (0 to 50 lux)	Typical Office (200 lux)	Operating Room (1000 lux)
X-ray film	0.03	< 1.5	4 to 6	20 to 30
CRT	0.02	< 1	4	20
LCD	0.006	<0.3	1.2	6

*Chawla and Samei, Med Phys, 2006

Influence of Ambient Light

Optimum level: 25 to 40 lux

McEntee et. al., SPIE 6164, 2006

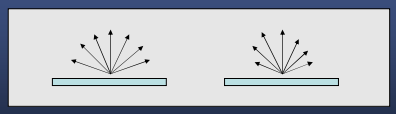
7 JND lost compared to dark environment of 400 to 600 available

Viewing Angle

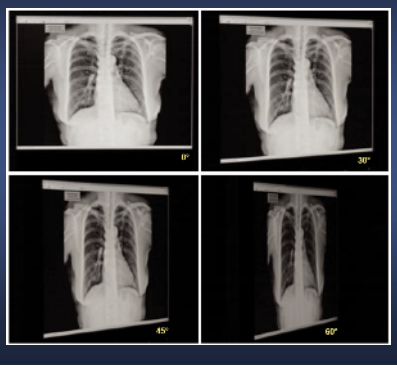
Non-Lambertian surface

Luminance and contrast (and color) change as a function of viewing angle.

Lambertian non-Lambertian

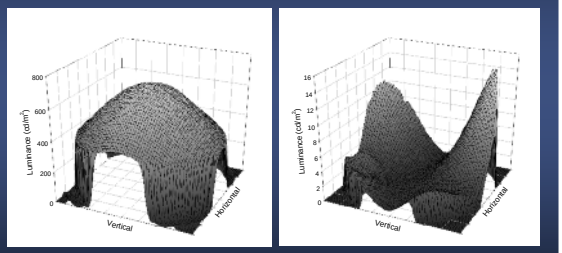


Visual Influence of Viewing Angle



Luminance vs. Viewing Angle

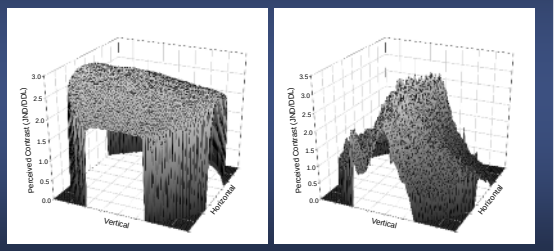
DDL = 255 DDL = 0



Axes Range: -40º to 40º

JND Contrast vs. Viewing Angle

DDL = 240 to 255 DDL = 0 to 15



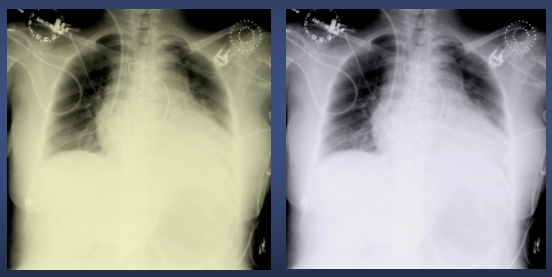
Axes Range: -40º to 40º

Color Tone

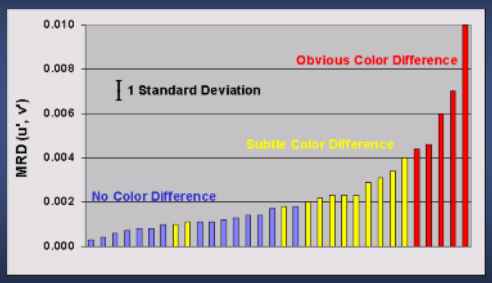
Color tone differences between displays can affect perception of contrast

- Can be distracting in a multi-monitor workstation
- Includes grayscale and color displays
  - Grayscale- changes in backlight color tone
  - Color- tone controlled by calibration

Color Tone and Perception



Color Just Noticeable Difference



V. Matching the Display to the Task

- Image vs. Display Matrix Size
- Image vs. Display Noise
- Color vs. Grayscale
- Viewing Distance
- Ambient Light Conditions
- Diagnostic or Case Review

Image vs. Display Matrix Size

Display of every image pixel is desirable.

- Especially MR, CT, US, …
- For CR/DR, zoom allows full resolution

Need to consider screen layout.

- 1 MR image per display- 1024x768 display
- 6 MR images per display- 1200x1600 display
- 12 MR images per display- 1536x2048 display

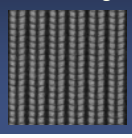
Image vs. Display Noise

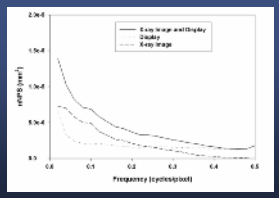
Image noise should dominate display noise.

- Avoid adding systematic degradation to the imaging chain.

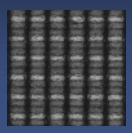
Image vs. Display Noise

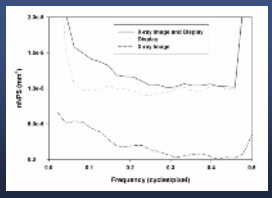
Medical Imaging





Consumer





Color vs. Grayscale

Some modalities use color in images

US, CT reconstruction, functional MR

What about grayscale images?

A grayscale LCD is a color LCD w/o color filters

Grayscale vs. color monitor is irrelevant…

as long as it is calibrated, low noise, etc

Grayscale monitors are brighter

Color monitors are catching up

Viewing Distance

Affects display size and pixel pitch requirements.

Radiology Reading Room

Distance: 50 cm typical

LCD Size: 21”

Optimal or practical?

Operating/Emergency Room

Distance: 50 cm to 3 m.

LCD Size: 21” to 40”+

Ambient Light Conditions

Reading Room Recommended

25-40 lux (McEntee et. al., 2006)

Standard Office

200 to 400 lux

Operating Room

800 to 1200 lux

Ambient Light Conditions

Display Reflectance

- Inherently low for LCDs, but high for some with protective cover panels

Reflected Luminance

- Compromises dynamic range and low-luminance contrast

Ambient Light Conditions

Recommendations

- Keep ambient as low as possible given the clinical circumstances
- Use indirect “soft” lighting
- Use spot lighting
- Avoid direct illumination of display
- Avoid direct illumination of human eye

Diagnostic vs. Case Review

Diagnostic- “Medical Imaging Grade”

- Grayscale calibration
- Low visual noise
- Appropriate resolution
- Luminance stabilization
- Free from artifacts
- QC Schedule

Diagnostic vs. Case Review

Case Review

- Assumes that Radiology report is available
- Grayscale calibration required
- Consider specific clinical use, may require Diagnostic quality
- Same considerations as Diagnostic, but performance requirements may not be as high

Grades of Displays

	Medical Imaging	Professional	Consumer
Calibration	Yes	Yes	3rd party
Lum Stablization	Yes	No	No
Remote Monitoring	Yes	Limited	No
Quality Guarantee	Yes	No	No
Image Quality	Highest	Variable	Variable

VI. Assessing and Maintaining Quality

- AAPM TG-18
- Pre-purchase evaluation
- Acceptance Testing
- Routine Quality Control
- Warranty
- Practical Examples

AAPM TG18 Report

Assessment of Display Performance for Medical Imaging Systems

- CRTs and LCDs
- Qualitative and Quantitative tests
- Basic to sophisticated
- Quick to resource intensive

Tests to Ensure Quality

	Purchase Evaluation	Acceptance Test	Routine QC
Cleaning	X	X	X
On-hours	X	X	X
Reflection	Quant	-	-
Lum Response	Both	Both	Both
Lum Uniformity	Both	Both	Qual
Resolution	Both	Qual	Qual
Visual Noise	Both	-	-
Veiling Glare	Quant	-	-
Chromaticity	Both	Both	Qual
Artifacts	Both	Both	Qual

Routine QC

- Remote Luminance Monitoring
  - Monitors luminance via built-in photometer
  - As good as the built-in photometer
- On-site Evaluation
  - TG18- 1 to 3 months
  - Practical for LCDs- 3 to 6 months

Routine QC

- Use clinical display software
  - Tests entire imaging system, not just displays
- Adaptable
  - Customize QC process to accommodate technology and circumstances

Warranty

- Understand the manufacturer's warranty
- Acceptance test against specifications
- Are replacement displays new or used?
- Medical Imaging Grade LCDs
  - Performance based warranty, 3-5 years
    - Luminance, artifacts, etc.
- Consumer Displays
  - Functional warranty, 1 year

Example 1: Evaluating Luminance Response

	Quantitative	Qualitative	Time Required
Pre-purchase Evaluations	256 steps	Grayscale ramp Low-contrast targets	4 Hours
Acceptance Testing	18 steps	Grayscale ramp Low-contrast targets	10 min
Routine Quality Control	5 steps	Grayscale ramp Low-contrast targets	5 min

Example 2: Maintaining Maximum Luminance

Medical Imaging Grade LCDs

- Calibration is stored on the monitor.
- Built-in photometer and feedback circuit to maintains luminance.
- Front of screen and/or backlight meters.
- Luminance maintained to within 5%.
- GSDF calibration is stable.

Example 2: Maintaining Maximum Luminance

"Professional" grade displays

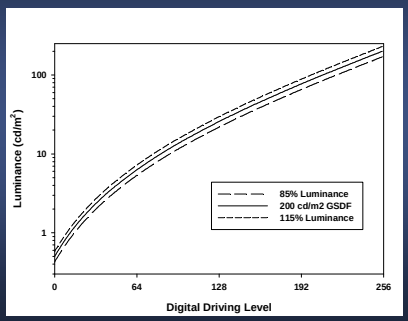
- Calibration is stored on the monitor.
- *No* built-in photometer and feedback circuit to maintain luminance.
- Luminance falloff due to natural backlight degradation.
- How should luminance be managed?

Example 2: Maintaining Maximum Luminance

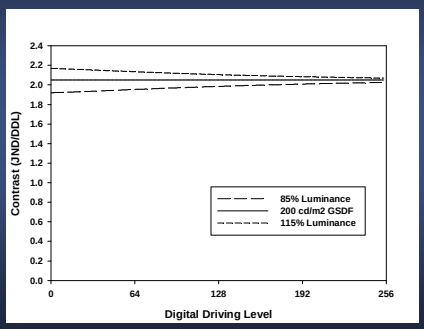
The plan

- Calibrate the display to 200 cd/m^2
- "Overdrive" the luminance by 15%
- Allow luminance to decay to -15%
- How does this influence GSDF conformance?

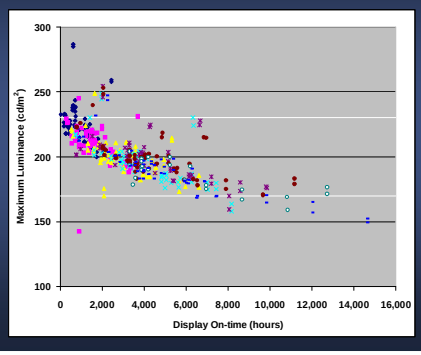
Example 2: Influence of "Over" and "Under-Driving" Luminance



Example 2: Influence of “Over” and “Under-Driving” on Contrast



Example 2: Luminance Change over Time



Summary

- Consult the literature
- Understand how the display will be used clinically
- Understand benefits and limitations of displays
- Construct a quality maintenance program
- Customize quality maintenance program based on clinical use and LCD properties