Introduction to Current Display Technologies for Medical Image Viewing

Perspectives for the TG270 Update on Display Quality Control

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Parsing our Options for Medical Image Display

- Overview of current display technology
  - How different display types work
  - Perceptually relevant hardware characterization
- Display features for medical imaging
- What's on the market and market trends

Technology changes

Not so long ago….

- When AAPM TG18 report was started, most of the soft-copy displays in medical imaging were CRTs.
- LCD and OLED were labeled as "emerging technologies"

American Association of Physicists in Medicine (AAPM) Task Group 18. 2005. Assessment of display performance for medical imaging systems. http://www.aapm.org/pubs/reports/OR_03.pdf./

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Today

Image source: https://betanews.com/2011/11/14/cea-keeps-up-search-for-cheap-safe-way-to-recycle-old-monitors-tvs/

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Today

Large Format LCD

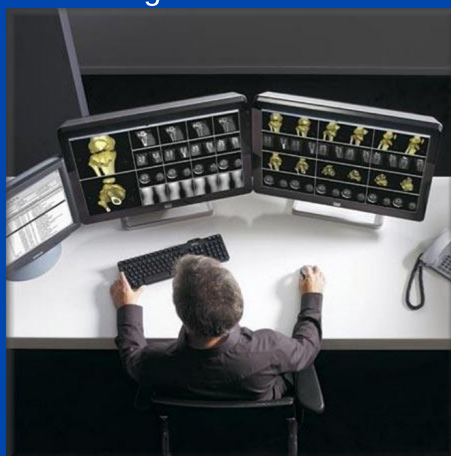


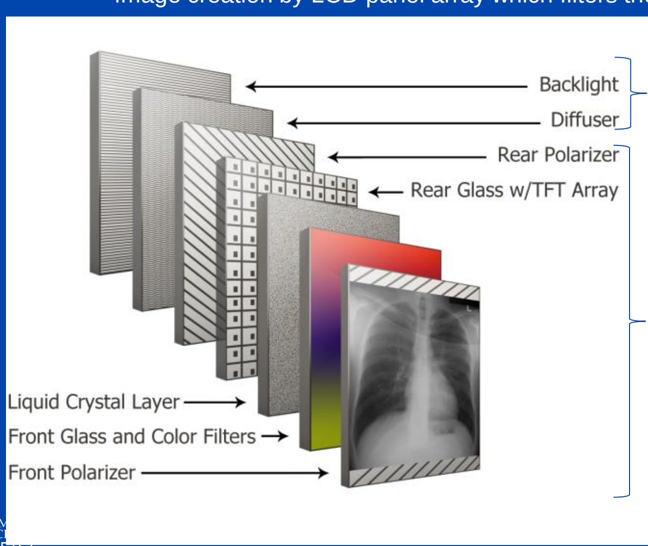
Image source: Barco

Small Format LCD and OLED

http://amiil.engineering.asu.edu/wiki/doku.php?id=projects:resmd

Liquid Crystal Displays (LCD)

Light source = backlight
Image creation by LCD panel array which filters the light output



"backlight"

Creates the uniform light source

"LCD stack"

spatial array of light filters used to create an image.

Pixels are created by TFT array, which locally affects the light polarization determining how much light passes through

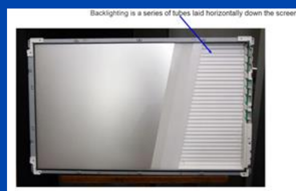
TFT = thin film transistor

Liquid Crystal Displays (LCD)

Luminance : the light emitted from a display

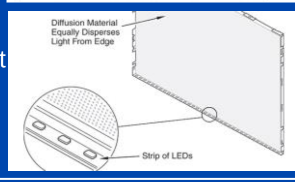
Common backlight configurations (CCFL or LED)

CCFL bulb array



Older models

Edge-lit LED

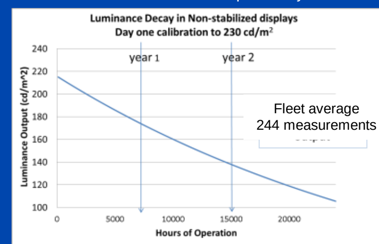


Current models

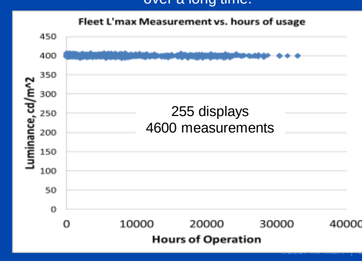
Medical grade displays use bright backlights with headroom to maintain calibration over time

brightness typical	1000 cd/m2
calibrated brightness	500 cd/m2

Consumer grade: backlight not as bright
Max Luminance output decaysi



$$$ Medical Imaging Displays have brighter backlights. Displays can be maintained at constant max luminance over a long time.



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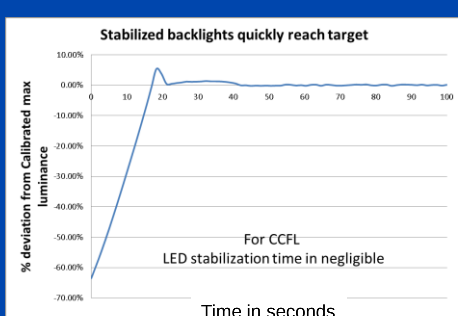
Liquid Crystal Displays (LCD)

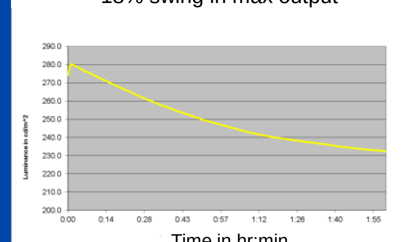
"Medical-grade" diagnostic displays have backlight stabilization (sensor that monitors backlight output).

Display luminance quickly gets to target and stays there.



Don't need long warm up times = save your backlight and your time

without backlight stabilization (CCFL)
18% swing in max output



When are you measuring? Luminance changes. QC headache

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Liquid Crystal Displays (LCD)

- Display luminance loss over time can also be caused by aging of other components.
- What the backlight sensor sees is not what the viewer sees (or a front panel photometer).
  - we saw this when we didn't have integrated photometers and hoped to make our lives easier with reliance on the backlight sensor for stable front panel output. Didn't work that well.
- It's necessary to make front panel measurements on a regular basis and recalibrate the display.

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LCD image formation

fixed pixel matrix

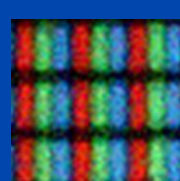
Image is creating by blocking the backlight.
Millions of little shutters

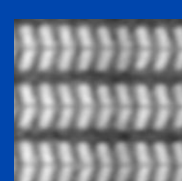
How much light is transmitted depends on the voltage applied to the pixel.

Minimum Luminance = maximal blocking

Maximum luminance = minimal blocking

Separately addressable subpixels with RGB filters combine to make different colors.





Monochrome may have same underlying subpixel structures just without the color filters

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Variation in pixel responses to the same driving level means noise

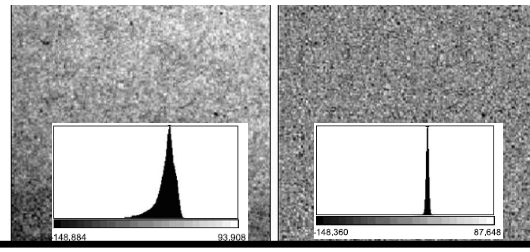
Higher quality panels have greater uniformity and less noise

Medical grade diagnostic displays often employ -pixel correction factors to reduce fixed-panel noise

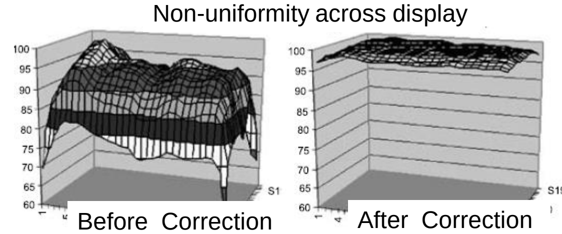
Pixel correction also can correct for non-uniformity in backlight illumination of the LC panel

Source images from: Kimpe, T et al. JDI, 18: 3 (2005)

Noise	No P-P correction	P-P correction
Std.Dev	12,590	2,403



Non-uniformity across display



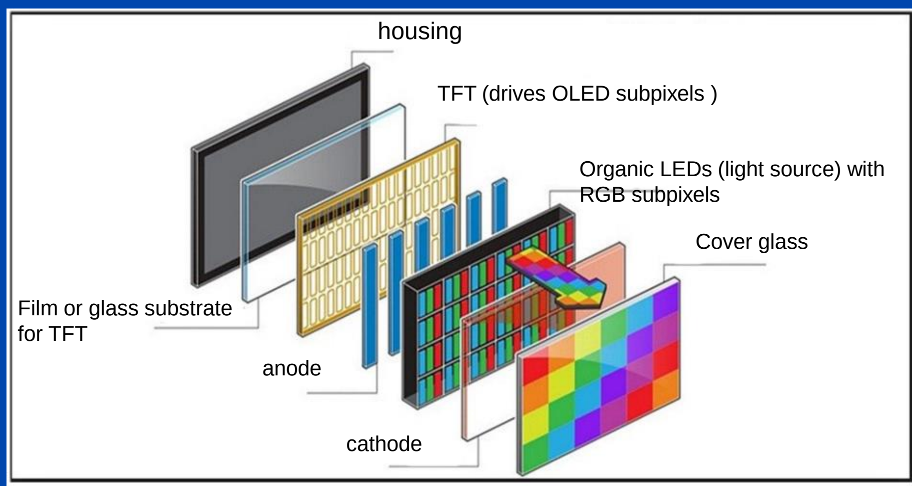
Before Correction After Correction

LCDs currently dominate the display market for diagnostic medical imaging

Everything LCD

Images from Barco, Eizo and Double Black product websites

Organic Light Emitting Diode (OLED) displays



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OLED image formation
fixed pixel matrix

Each pixel is a separate emissive element (OLED), controlled by a TFT array.

(No backlight)

Black = Black = pixel is off (no light)

Color comes from either subpixels of RGB OLED (shown) or White OLED subpixels with color filters .

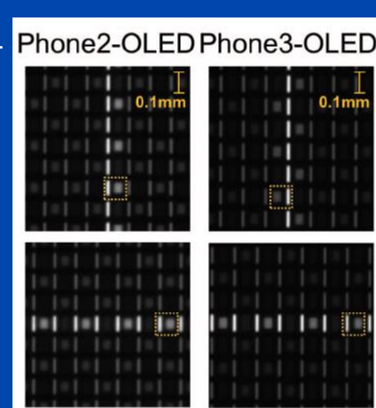

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Image source: Yamasaki et al., Spatial resolution and noise in organic light-emitting diode displays for medical imaging applications Opt. Exp. (2013).

OLED display vs LCD display

What was looked at	
OLED displays	Handhelds and **one** workstation monitor
LCD	Handhelds and workstation monitors

Refs:
Yamasaki et al., Opt. Exp. (2013).
Elze, et al. Med. Phys. 40 (9), September 2013

What was found	
Luminance Ratio	OLEDs have higher luminance ratio because of dark black level. [LCD workstations still win max luminance but that is changing]
Resolution	Comparable within handheld class OLED workstation had worst resolution (signal contamination between pixels)

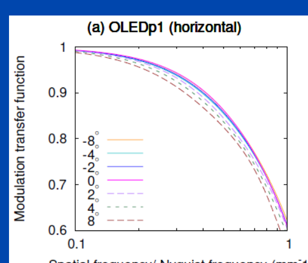
OLEDs had resolution and noise variations that varied with luminance (attributed to sub-pixel rendering method).
[May be different with subpixel structures to be employed in future OLED workstation monitors]

[not from reference, my own commentary]

Factors that impact resolution for OLED displays and LCD

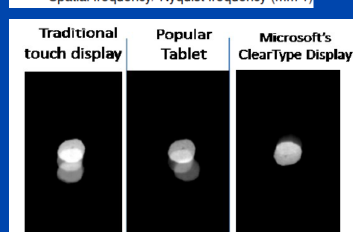
- Viewing distance (perceived resolution changes with distance)
- Viewing angle
- Luminance level*,**
- Pixel design*,**
- Panel reflections

	Viewing Distance inches (cm)	Pixel Pitch µm per pixel
Small handheld	10 (25)	78
Tablet handheld	15 (38)	117
Laptop	20 (51)	156
Workstation	25–35 (64–89)	195–273
Consultation	40 (102)	312



Impact of viewing angle

*Yamasaki et al., Opt. Exp. (2013).



Impact of internal panel reflections on resolution

S.Bathiche, et al. SID 2013 DIGEST

**Yamazaki, et al. PLOS One, 2013. 8(11)

Where is the OLED ?

Largest market for OLEDs today
Potential utilization: telerad, consult with mobile viewers

Where is the OLED monitor ?

Available 2017

Dell 30 UltraSharp OLED Monitor

Pixel Pitch
0.173 mm x 0.173 mm
Brightness
300 cd/m^2 (typical)
Maximum Preset Resolution
3840 x 2160 = 8MP

Cannot be calibrated ☹

Sony PVM-2551MD
Pixel Pitch
0.283 mm x 0.283 mm
Brightness
???
Maximum Preset Resolution
1920 x 1080 pixels = 2 MP

Cannot be calibrated ☹

Available 2012

Where is the OLED for diagnostic imaging workstation?

Possible hold ups? Resolutions needed to be worked out for:

- Signal retention
- Luminance artifacts and color shift of OLEDs
- Desired max luminance
- End user calibration options
- Infrastructure for panel production for niche

Evaluation of only OLED workstation for medical market found *:

- For single color primaries, up to 50.5% of the luminances of neighboring display values were not perceptually distinguishable
- Luminance saturation effects were observed when too many pixels were active simultaneously. Full screen saturation at 162 cd/m^2

Issue with OLED display is image retention (burn-in). Each pixel ages differently - the brightness is reduced with use. A pixel that was used a lot will be less bright than a pixel that hasn't been driven as much [https://www.oled-info.com/oled-monitor]

* Ref: Elze, Taylor, and Bex. Organic light emitting diode monitors for medical applications, Med. Phys. 40 (9), September 2013

More OLED workstation monitors on the market for medical image display soon?

Sony may be JOLED's first customer for its 21.6" 4K medical OLED monitors

Jun 08, 2017

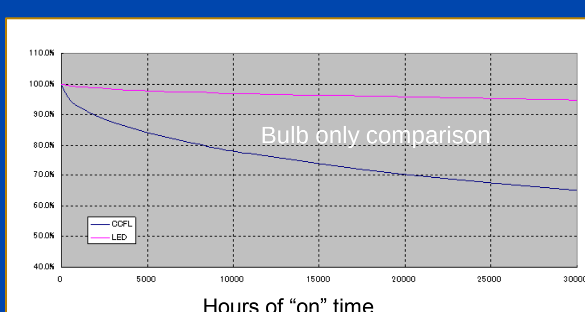
Last month JOLED announced that it started to sample 21.6" 4K OLED monitors. JOLED plans to develop these OLED monitors for medical applications - it will produce these in low volume at its current 4.5-Gen pilot production line, and will start mass production in 2019.

https://www.oled-info.com/oled-monitor

Trends (or trended)

the Market Place For Diagnostic Imaging

LED backlights: the better LCD option for longevity



LED backlights have superior lifetime and efficiency compared to CCFL

Practice Anecdote:

37,000 hours of operation And still showing 100% backlight

Source: Eizo, reproduced with permission

the Market Place For Diagnostic Displays

- Integrated Photometers and software for automated monitoring and calibration

Displays for medical imaging need to be monitored and occasionally re-calibrated to maintain performance. These tools have the *potential* to make that easier

PHOTOMETERS	
Integrated Photometer: Measures one location Can be used for automated testing	Hand-held photometer: Can measure multiple locations Can be used to "calibrate" integrated photometer And measure display uniformity

Image source: Eizo

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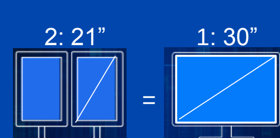
the Market Place For Diagnostic Displays

- Larger Format Displays

An increasingly popular option associated with increased efficiency and flexible work space utilization, replacing multiple heads.

Image Source: www.barco.com/en



2: 21"	1: 30"
2MP	4MP
3MP	6MP
5MP	8MP
	10MP
	12MP (33")

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the Market Place For Diagnostic Displays

- Color

Medical images and viewing software increasingly use color to increase information density or for aid in visualization.

Older generation color LCD lacked the max luminance provided by monochrome. This is no longer the case, even for mammography which is typically set with the highest luminance.

Many brand options
For 6MP color

Barco	Double Black Imaging	EIZO Inc.	Quest International, Inc.	Richardson Healthcare
Coronis Fusion 6 MP	DBI6MPLED - 6 MP color LED system	RadiForce RX660	CCL650i2	Image Systems XLED 6MPC

And NEC and WIDE

Image Source: https://www.itnonline.com/compare/69711/50503?products=2-7-16-19-28-33

the Market Place For Diagnostic Imaging

- Higher brightness
  - ACR used to recommend 171 cd/m^2 max calibrated (currently 350 cd/m^2)
  - Typical diagnostics display currently have 350-500 cd/m^2 max calibrated
  - Some diagnostics displays reach 1000cd/m^2 max calibrated
- Higher brightness displays can allow for
  - higher ambient light environments*
  - multimodality viewing including mammography

(*would be great for clinical and surgical viewing)

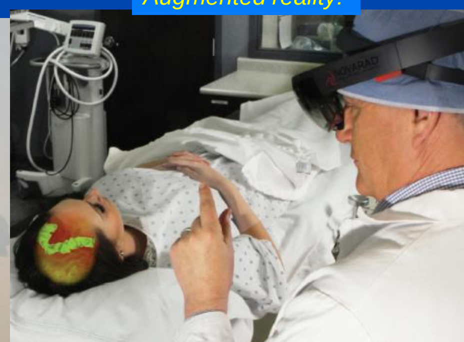
Tomorrow?

There are many workflow challenges in integrating more information and different kinds of information (radiologic, path, radiomics data, data from image analytics like CAD, 3D renderings) for different use cases in better quality and more efficient formats.

Flexible displays:
TFT glass replaced by TFT film

Image source: https://www.digitaltrends.com/home-theater/lg-display-55-inch-flat-oled-panel-sticks-to-wall-with-magnet//

Augmented reality:



https://www.novarad.net/opensight/

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As new viewing solutions develop to meet new diagnostic challenges

There is work for physicists with radiologists and other imaging scientists and engineers

To *characterize devices and guide operation and maintenance*

In order to best deliver quality imaging that

- Maximizes information delivery
- Provides consistent image display, and
- Works with perceptual and cognitive limitations of the viewer

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Questions & Discussion