

LCD VS CRT TEACHING CLASS

FEBRUARY 7TH, 2003
STORCOMM, INC. HEADQUARTER

SYLLABUS

Agenda:

- 10:30 Introduction
- 10:35 Human visual system as part of imaging chain - Tibor Duliskovich
- 11:00 Advanced Monochrome technology for the medical application LCD monitor - Toshihiko Furukawa
- 11:30 Demonstration of 1.3 MP (11 bit), 2 MP (8 bit) and 3 MP (8 bit) LCD displays - Toshihiko Furukawa
- 11:00 The brightness setting for the medical application LCD monitor - Toshihiko Furukawa
- 12:20 Pizza break
- 12:40 Alternative technologies and LCD specific calibration problems - Tibor Duliskovich
- 12:50 LCD or not to LCD? - Tibor Duliskovich
- 13:00 Closing the session

Human Vision as Part of Imaging Chain

Tibor Duliskovich MD
7th of February, 2003

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Agenda

- Imaging chain from acquisition to report
- Anatomy of human eye
- Physiology of human eye
- Spatial resolution of eye
- Color vs monochromatic monitor
- Pixel structure of LCD vs CRT
- Hard vs softcopy reading
- Visual Operating Systems
- LCD specific calibration problems
- LCD advantages
- CRT advantages

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Imaging chain from acquisition to report

- Source of energy (electro-magnetic waves, sound, etc.)
- Energy modulation (collimation, grid, static magnetic field)
- Patient anatomy and contrast agent
- Analog detector (film, gaseous, crystal, ionization chamber)
- Pre-processing (amplification or A/D conversion)
- Display device and environmental conditions (light box, CRT or LCD, ambient light)
- Image post-processing (mag. glass, edge enhancement, equalization, 3D, MPR, etc.)
- Human eye and visual cortex
- Interpretation of the image based on experience or CAD
- Creation of textual report – the final product

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Conventional vs Digital Imaging

	<i>Conventional Imaging</i>	<i>Digital Imaging</i>
<i>Capture</i>	Film in cassette	X-Ray detector, antenna, US transducer
<i>Post-processing</i>	Lupe on film, spot light	Software
<i>Display</i>	Film on light box	Monitor
<i>Storage</i>	Film in jacket	Optical or magnetic, tape or disk archive
<i>Transportation</i>	Film in hands of rad tech	Network, removable media
<i>Hardcopy</i>	Another sheet of film	Printed film

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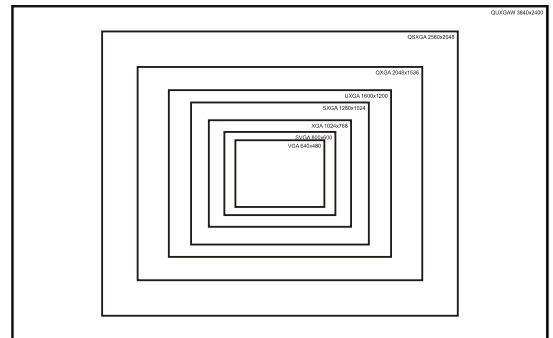
Types of radiological images

- Transparent (film) and opaque (Polaroid, US)
- Double and single emulsion coating films
- High and low speed films (screens)
- Different sizes and resolutions
- Color and BW images
- Motion images
- Only softcopy



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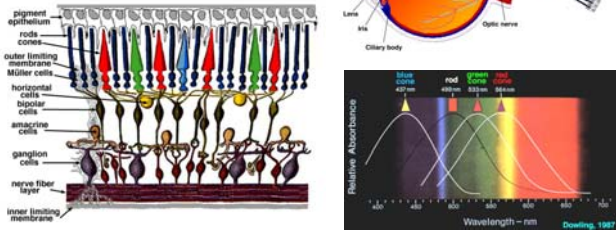
Display resolutions



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Anatomy of human eye

<http://webvision.med.utah.edu>



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Physiology of human eye

- Cones:
 - 6.5 million cones in human retina
 - responsible for light or photopic vision (above 1-10 cd/m²)
 - cones are only present in fovea centralis
 - each individual cone has a representation in visual cortex
 - high spatial resolution, good vision of objects
 - 3 types of cones for color vision:
 - blue 445 nm
 - green 535 nm
 - yellow 570 nm light sensitive (so-called red cones)

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Physiology of human eye

- Rods:
 - 125 million of rods in human retina
 - low-light level or scotopic vision (below 1-10 cd/m²)
 - higher number on periphery of retina than in fovea centralis
 - signal from few hundred rods is converged and summarized in a single nerve connection (signal-to-noise ratio improvement)
 - inferior spatial resolution and no color vision
 - great light sensitivity (0.75×10^{-6} cd/m², light coming from a candle 30 miles (50 km) away = 6 lightphotons/sec!)
 - non-sensitive to red light (that is why radiologist used red adaptive glasses half century ago!)

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Spatial resolution of human eye

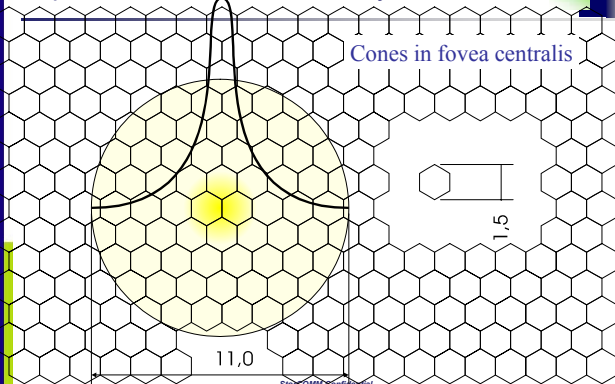
- Spatial resolution means the smallest angle when we can distinguish between two adjacent bright spots
- A dot-like light source smallest representation on retina is a light spot with diameter of 11 μ m, because of chromatic aberration and diffraction
- Diameter of a cone cell is 1.5 μ m
- Bulbous is performing a continuous mikrotremor with amplitude of 1 angle-second and frequency 80-120 Hz, that is why a dot-like light source representation on retina will spread in addition even more over 2-4 cones



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Spatial resolution of human eye

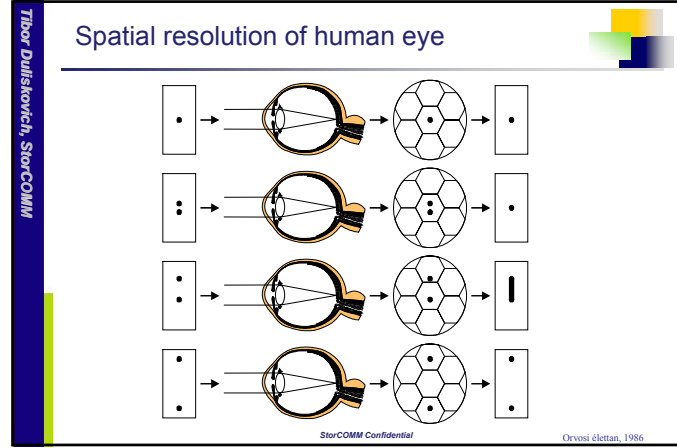
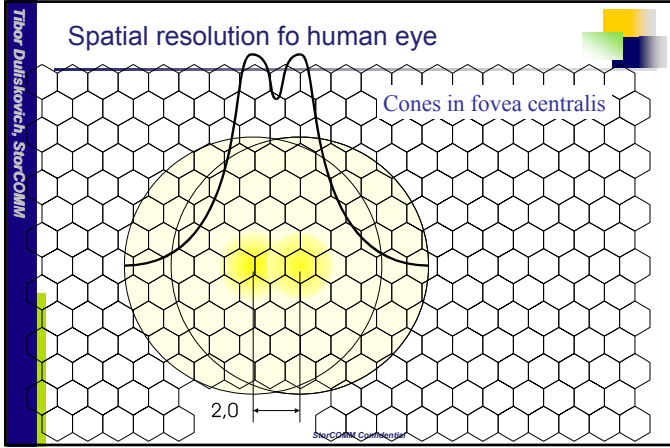


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Spatial resolution of human eye

- One can differentiate between two close light spots if there is at least 2 μ m wide darker space between them on retina (at least 1 cone cell with lower signal)
- Theoretically the ideal spatial resolution of human eye is 26 angle-seconds in case of high contrast pattern
- In real world the resolution is limited to 1 angle-minute
- From distance of 27 inch (70 cm) 1 angle-minute means spatial resolution of 0.2 mm
- A 17" monitor screen dimensions are width 280 mm, heights 215 mm
- Which means on a 17" monitor one can resolve a 1400x1075 matrix (1.5 megapixel) from 27 inch distance with naked eyes. On larger surface a little bit more

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Physiology of human eye

- Human eye is capable of resolving only 32-64 gray-scale steps, that is why windowing is the most essential feature in reading of images with $2^{16} = 65.536$ gray scale levels
- Latency time of light reflex (iris reaction time) is app. 0.2 sec and it is capable to reduce the incoming light quantity only be factor of 1/16 (film on light box)
- The lowest detectable light intensity is 10^{-9} lux
- The highest tolerable light intensity is 10^6 lux
- To different lighting conditions human eye is adopting by changing the amount of rhodopsin in light sensing cells, which takes 8-20 minutes normally

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Contrast sensitivity and DICOM

- JND index is "perceptually linearized", meaning same change in input is perceived by the human observer as the same change in contrast

Grayscale Standard Display Function

Luminance cd/m²

JND Index

Monitors

Film

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Perceptual Linearization

Grayscale Standard Display Function

log10 in luminance cd/m²

JND Index

Despite different change in absolute luminance

Same change in input is perceived by the human observer as the same change in contrast

Same number of Just Noticeable Difference = Same perceived contrast

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Physiology of human eye

- The reaction time of accommodation (focusing at different distances) is app. 0.3 sec and the time needed to accommodate is another 0.5 sec (monitor-keyboard-film)
- Ciliary muscle is not capable of complete relaxation, so the relaxed eye is focused in a distance of around 40 inches (1 meter), that is the best distance to look at monitor or light box
- The eye can differentiate between colors with wavelength difference of as little as 10^{-7} nm
- Only 1 million nerve connection exists between retina's 6.5 million cones and 125 million rods and visual cortex (data compression occurs before transportation)
- Each cell of fovea centralis - the place of clearest vision - is represented at least 5 times at different places in visual cortex (similarly to multi-processing in modern computers)

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Pseudo-coloring

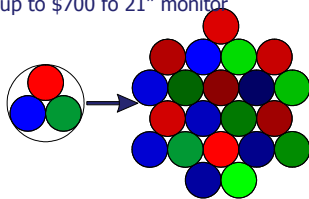
- Evidence suggests that color has a much broader dynamic range than gray scale - 500 just noticeable differences (JND) versus 60 to 90.
- But the human visual system has lower spatial resolution in the color channels than in the luminance channels.
- Attempts to increase dynamic range by going to color may therefore be confounded by color luminance dependencies. Human performance in signal detection is best for gray scale followed closely by the color-heated object scale. Performance with all other color scales tested fell by 25% to 30%.

Noise perception

- Motion image (Ultrasound, Fluoroscopy, etc.):
 - low resolution
 - motion image
 - very high noise (low signal/noise ratio)
 - slow response of human eye will integrate the noise, perception is - good image quality (until you freeze one frame!)
- Still image (X-ray, CT, MRI, etc.):
 - high resolution
 - still image
 - relatively low noise (high signal/noise ratio)
 - very visible static noise pattern, perception is - noisy image
- Noise is always present in any medical image, because of physics of imaging, but how much is too much?

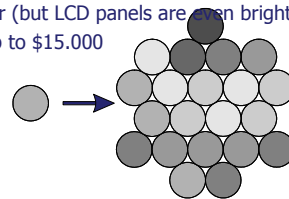
Color PC monitor

- 3 mask holes = 1 pixel, app. 3x0.22 mm, 3 spots = 1 pixel
- Lower resolution
- Phosphor optimized for all three colors
- Lower contrast ratio = bit depth (8 bits)
- Low brightness
- Cost up to \$700 for 21" monitor



Diagnostic quality monochrome monitor

- no mask, 1 pixel size app. 0.2 mm, depends on electronic optic (focusing), 1 spot = pixel
- Higher resolution
- Optimized fluorescent layer
- Higher contrast ratio = bit depth (10 bits)
- Brighter (but LCD panels are even brighter !)
- Cost up to \$15.000



Typical Medical Gray-Scale CRT specs

- peak luminance of 204 FL (or 700 cd/m²), 190 FL (650 cd/m²) nominal
- contrast ratio 1000:1 ???
- pixel afterglow 50 msec or less (depends on phosphor)
- luminance uniformity ($L_{\text{dark}}/L_{\text{light}}$) 95% over a circular area of 10 mm diameter placed anywhere on screen and is 85% over the entire screen
- wide viewing angle of 180 degrees both horizontal and vertical - Lambertian distribution (with contrast slightly dropping to the end)

LCD vs CRT pixel shape



3MP LCD
subpixel structure

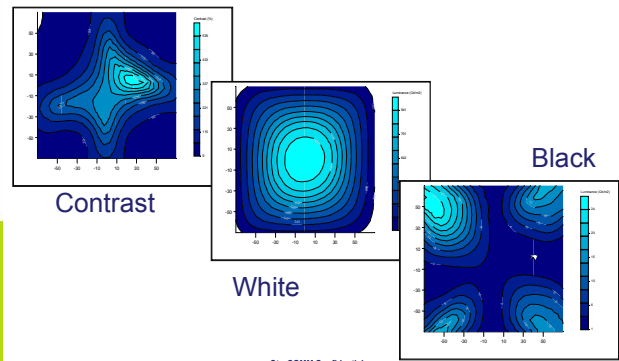


2 MP CRT
pixel structure

Typical medical LCD specifications

- peak luminance of 204 FL (or 700 cd/m²), 190 FL (650 cd/m²) nominal
- contrast ratio 600:1
- optical rise time/fall time 25/25 msec (the time to switch pixels on/off)
- luminance uniformity ($L_{\text{dark}}/L_{\text{light}}$) 80% over a circular area of 10 mm diameter placed anywhere on screen and is 60% over the entire screen
- wide viewing angle of 170 degrees both horizontal and vertical (with contrast dropping to 10:1 on ends)

Viewing angle dependencies on LCD



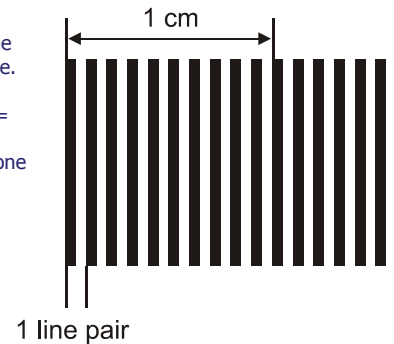
Hardcopy vs Softcopy Reading

- Same number of JNDs on film or display
- Potentially inconsistent appearance on images across workstations and printers
- Full dynamic range on display with windowing tools
- Limited post-processing with hardcopy
- About 20% of the radiologist's attention, as measured with eye-position recording, is spent looking at non-image menu areas when reading from screen
- According to studies reading from low resolution monitor is 20-30% longer than reading from film or high resolution screen
- Reading from brighter screen is faster

Definition of resolution

One line pair means one black and one white line.

For example 10 lp/cm = 10 black and 10 white lines, the thickness of one line is 50 μm



Definitions

- Unit of luminance (light intensity emitted per unit area of screen in given direction):
1 fL (foot Lambert) = 3.426 cd/m² (candela per square meter)
- Unit of illuminance (light intensity incident on a surface per unit area):
1 fc (foot-candle or lumen per square foot) = 10.764 lux
- A bright dot (dead pixel on LCD) is a lit sub-pixel under all black background.
- A black dot (dead pixel on LCD) is an unlit sub-pixel under any bright raster.

Clinically required resolution

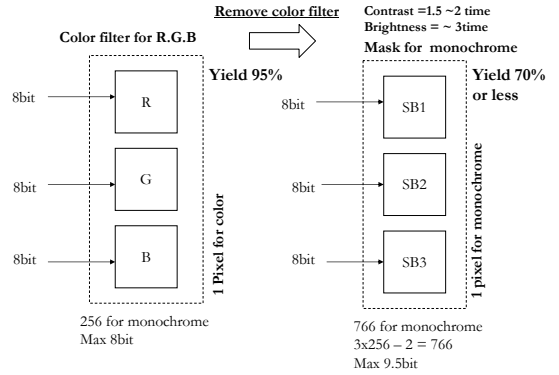
DSA		150 μm
Chest fluoro		250 μm
Gastro fluoro		250 μm
Chest film		200 μm
Bone image		100 μm
Mammography		50-70 μm

- Depends on type of exam
- According to ROC studies the diagnostic information is encoded in frequencies between 0 and 2 lp/mm !!!
- In case of mammography the requirements deviation is much higher than otherwise (image size up to 4600x6000 pixels 10 bit)

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Advanced Monochrome technology
for the medical application LCD monitor
from Data Ray Corp
Westminster CO

Color LCD to Monochrome



What's will be changed from Color

- Brightness jump up to 3 time
- Contrast jump up 1.5~2time
- It could increase gray shade level
- Resolution will never change
- The yield worse 3 times → cost up

What's different of LCD and CRT

	LCD(3M-pixel)	CRT(5M-pixel)
Contrast	Stable 700:1	Valuation depend on the APL 60:1~1000:1
Resolution	TFT mask size 100% MTF at 3M-pixel	Beam spot size 30%~40% at 3M pixel Less than 10% at 5Mpixel
Brightness	Back light 800cd/m ²	Anode power 600cd/m ²
Life	30,000 hr at 50% No focus change, MTF will be stable	Less than 20,000hr at 50% focus change MTF going down
Viewing angle	Contrast, Brightness change	No change

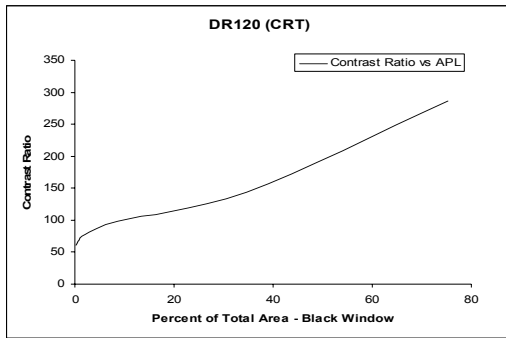
Disadvantage due to LCD characteristics

- 100% illuminate pixel defect
>>> Specification
- White shading at the black back ground
>>> Specification
- Variation of Color temperature
>>> select LCD panel
- Gray shading at medium gray level
>>> Specification

Variation of Contrast for CRT and LCD

Black Window Size, inches - HxV	Black Window Luminance, cd/m ²	Black Window Area - % of Total	Contrast Ratio
0.5 x 0.5	5.77	0.134945482	60.65857886
1 x 1	5.2	0.539781928	67.30769231
2 x 2	4.5	2.159127712	77.77777778
4 x 4	3.53	8.63651085	99.15014164
8 x 8	2.43	34.5460434	144.0329218
11.8 x 11.8	1.22	75.15923567	286.8852459

CRT contrast dynamic changing



Gray shade expand technology

SHG system : 1786 (gray shade) Data Ray's System
 $Y=7SB - 6$ SB: Sub-Pixel SHG(Super High Gray shade)
 Good enough for conformance to DICOM curve and no flickering problem
 $+1FRC=3571(10.8bit)$, $+2FRC=7141(11.8bit)$

Sub-Pixel system: 766
 $Y= 3SB - 2$
 Not enough for conformance to DICOM curve

FRC(Frame Rate Control system): 1021
 $Y= 8bit(SB) + 2bit - 3$
 Not enough for conformance to DICOM curve
 Flickering problem for future LCD panel ($Tr/Tf < 16ms$)

Sub-Pixel system + FRC
 $Y= 766 + 1bit(FRC) - 5 = 1531$ or
 Conformance to DICOM curve will be good and less flickering problem
 $Y= 766 + 2bit(FRC) - 5 = 3062$
 Flickering problem for future LCD panel ($Tr/Tf < 16ms$)

New technology Super High Gray Shade SHG Technology

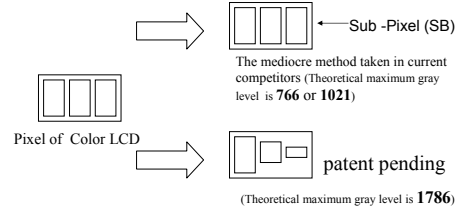
- Comparison with the makers who have already announced 3M pixel of LCD monitor.

Maker	DOME	BARCO	NationalDP	TOTOKU	Data-Ray
Theoretical gray level	766	1021?	766	1021	1786
Cinema mode	yes	no?	yes	no	yes

Data Ray 's SHG Technology

Our unique technology for monochrome LCD

- A unique technology to change an ordinal color LCD panel to high performance gray scale monochrome LCD panel.

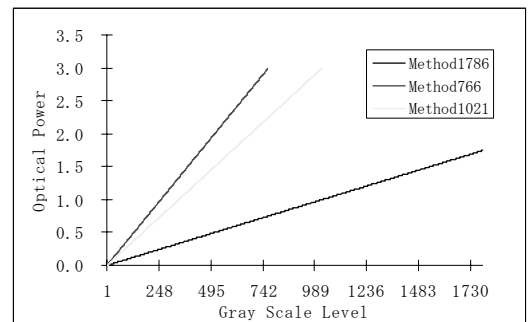


Three kinds of methods

- Method-1,(ND filter)
- Method-2,(MASK filter)
- Method-3,(FTT-metal)

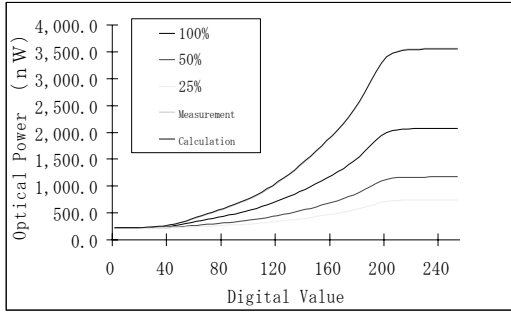


Theoretical value



Measurement result

- The experiment for 100%, 50% and 25% all added pixel's optical power with calculated one among 100%, 50% and 25% via offset subtraction.



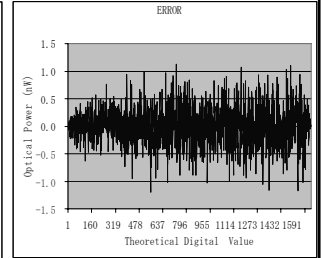
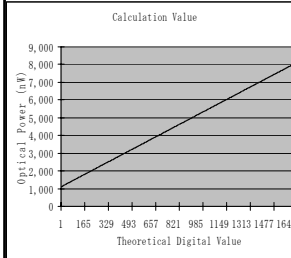
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Calculation result

- Theoretical value v.s. calculation value via basic experiment
The synthesized value calculated from experiment result is just around ± 1 error of about 1500 against theoretical value 1786.



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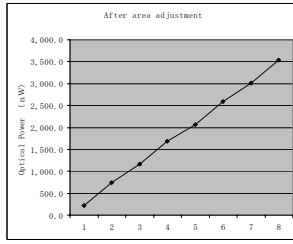
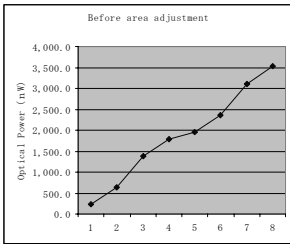
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Examination to light leaking



Method-2, (with MASK filter)

The measurement result

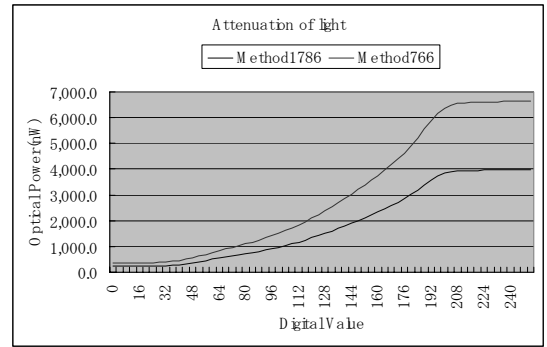


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Measurement value of attenuation

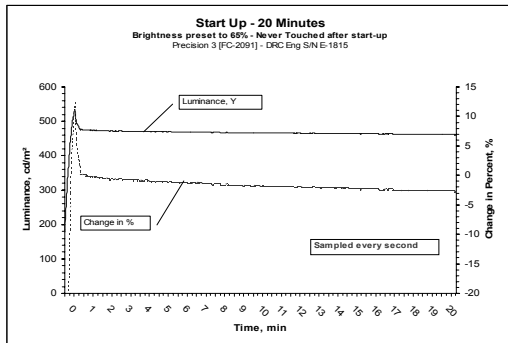


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Start up Brightness with built in Photo Sensor

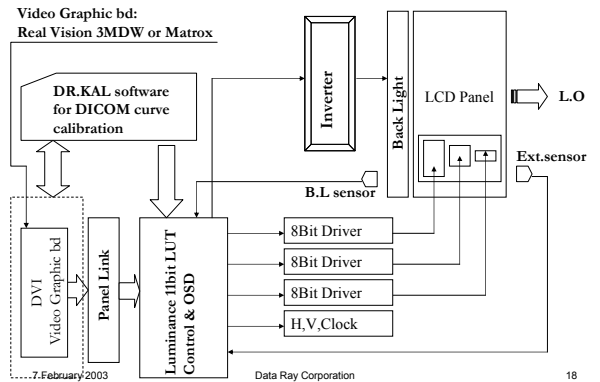


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System block diagram with SHG system



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DICOM conformance

- How accurate to the DICOM curve.
- #of JND need to be closer to equal# of each ADU
- STD DIV of #of JND for each step of ADU is smaller # is better.
- It will be an important parameter for the diagnostic purpose display monitor for PACS work station

Key factors for conformance

1. The source gamma characteristics of LCD device itself
2. The gray scale expansion technology
3. The accuracy of photo sensor
4. The proper coefficient need to be created for photo sensor to meet the LCD drive mode (IPS, MVA/ASV, TN)

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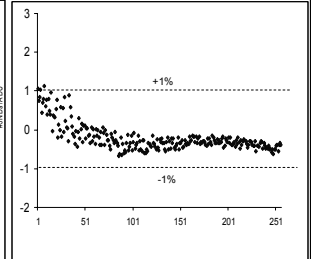
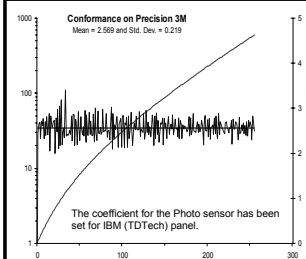
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DICOM conformance of Data Ray's System

PRECISION3's system
Sub-pixel + 1bit FRC(1531)
STD DIV: 0.219

PRECISION3's system
Sub-pixel + 1bit FRC(1531)
Error to DICOM curve



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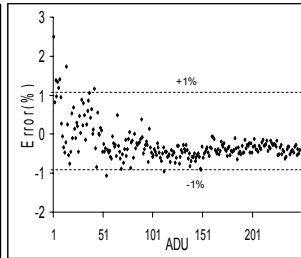
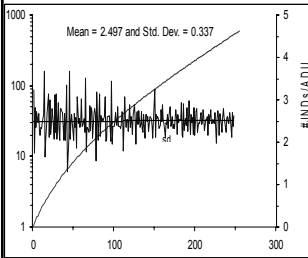
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The LCD gamma curve is not smooth

STD DIV: 0.331

Error to DICOM curve



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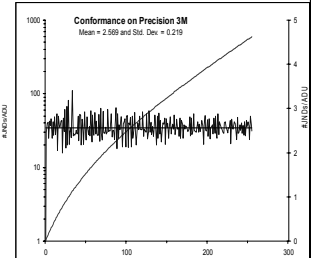
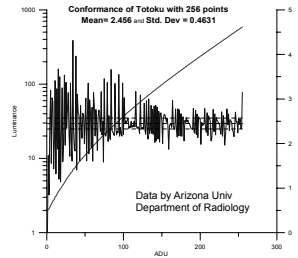
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The comparison of DICOM conformance

2bit FRC system(1021)
BARCO,Totoku,WIDE
STD DIV: 0.4631

PRECISION3's system
Data Ray Corp
STD DIV: 0.219



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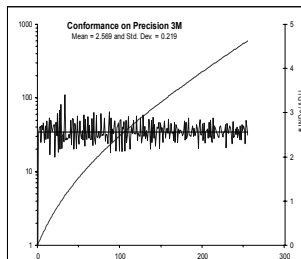
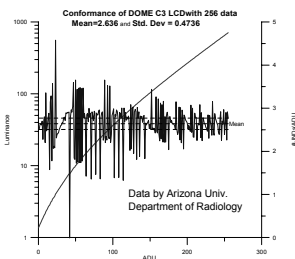
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DICOM conformance of the existing gray shade expansion technology

Sub-pixel system(766)
DOME
STD DIV: 0.4736

PRECISION3's system
Data Ray Corp
STD DIV: 0.219



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2M-pixel LCD monitor comparison Table

Vendor	Data Ray Corp	DOME	BARCO	Siemens *(1)	WIDE	TOTOKU
Nationality	USA	USA	EC	EC	KOREA	Japan
LCD panel	Sharp	Samsung	Sharp	Samsung	Samsung	Sharp
LCD technology	ASV *(6)	PVA *(7)	ASV	PVA	PVA	ASV
Hard ware PIVOT *(2)	yes	supported by Graphic board	yes	supported by Graphic board	supported by Graphic board	supported by Graphic board
Video input	Analog/DVI	DVI only	Analog/DVI	DVI only ?	DVI ?	Analog/DVI
Contrast ratio *(3)	800:1	700:1	800:1	700:1	700:1	800:1
Brightness *(4)	650 cd	700cd	600cd	700cd	700cd	700cd
Viewing angle *(5)	170 degree	170 degree	170 degree	170 degree	170 degree	170 degree
Palette	1531	3061	1021	1021	1021	1021
DICOM conformance *(8)	0.21	0.15	0.47	more than 0.47	more than 0.47	more than 0.47
Calibration soft included	yes	no	no	no	?	?
Luminance sensor built in	Back light	Back light	Front	?	?	Back light
Warranty	1.6 yrs for back light and 3 yrs for electronics	1 yr	?	?	?	?

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The brightness setting for the medical application LCD monitor

Data Ray Corp
Westminster CO.80234

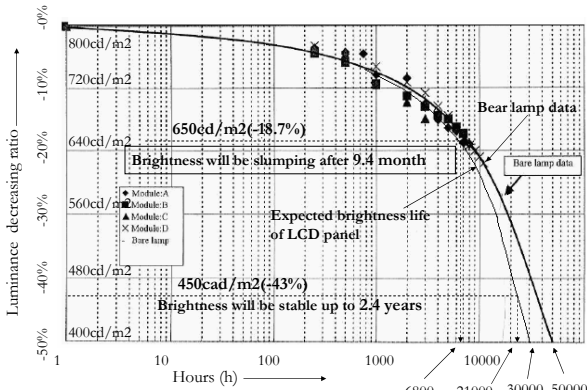
The recommendable setting brightness for the medical application LCD display monitor

450cd/m² to 550cd/m² should be recommended.

1. The brightness life expectancy will be over 1.6 to 2 years to maintain the setting brightness
2. Calibration for DICOM curve will be once a year will be enough, even less.
3. Products warranty can be over 2 years

Note: The calculation has been done as 24hr operating system

The brightness life expectancy



Warranty period study

The life data show on the graph is a typical cold fluorescent lamp life curve for LCD backlight. The life expectancy for brightness of LCD monitor will be determined by the backlight.

Case 1 : 800cd/m² No warranty will be given

Set brightness to 800cd/m² (Maximum rating for LCD panel specification) the brightness will be slumping every day.

1st day.....800cd/m²
3 month after720cd/m²
1 year after.....620cd/m² approx 1yr and 2 month

Case 2 : 650cd/m² No 1 yr warranty will be available

9.4 month after.....Brightness will start to be slumping

Case 3 : 450cd/m² 18 month warranty is very safe.

2.4 year.....Brightness will be stable.

The DICOM curve calibration for each case.

Case 1. 800cd/m²

LCD monitor need to be calibrate for DICOM curve for every month.

Case 2. 650cd/m²

Need to be calibrated for every month after 9.4 month.

Case 3. 450cd/m²

It will probably be once a year, even less.

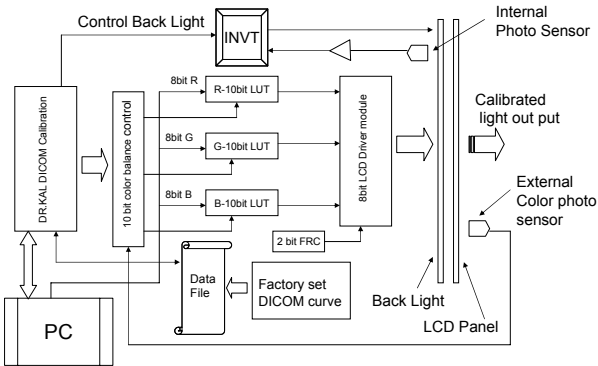
Theoretically no calibration will be necessary after the installation

Color LCD monitor for Medical Application

18" 1024x1024 and
20" 1600x1200(Hard ware PIVOT built in ?)

1. DICOM curve Calibration (Min 10bit accuracy)
2. Color balance Calibration (Min 10bit accuracy)
3. Luminance stability (Photo sensor feed back)
4. External Color photo sensor for LCD
5. 10bit LUT built in
6. IEC 601, CISPR-Class.B

Color LCD for Medical Application



END

Data Ray Corp
12300 Pecos Westminister CO80234

Alternative technologies and LCD specific calibration problems

Tibor Duliskovich MD
7th of February, 2003

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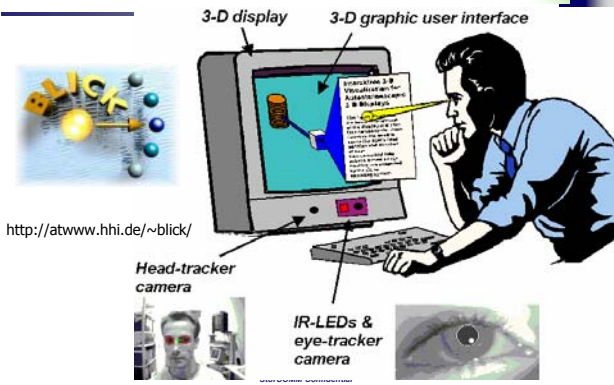
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Alternative Technologies

- Plasma Screens
- Light Emitting Diodes
- Micro-mirrors
- FED
- Nanotubes
- Flexible organic screens
- Projectors
- Wearable displays

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Future? Visual Operating System



Photometer

- A photometer is a device used to measure the intensity of light.
- The use of the human visual system as the detection model in creating an aim display function dictates different criteria for filtration selection. The integration of the model for the HVS dictates the sensitivity of the photometer to be correlated to the human eye-brain combination or HVS.
- The sensitivity of the average human observer is described as photopic. A filtration set used with a photometer that results in photopic sensitivity, integrates the light only over the visual light spectrum weighted by the sensitivity of the HVS.

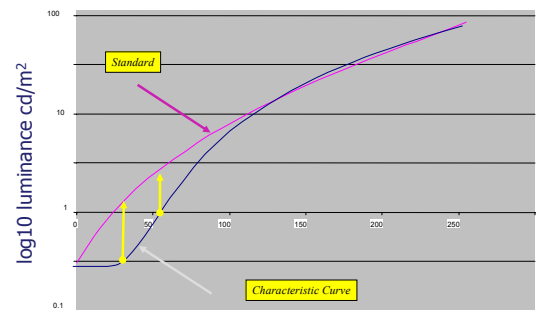
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Photometer

- The integration of multiple vendors' display systems also drives the need for a modified filtration set. A monitor manufacturer can vary several parameters in designing a display system. The phosphor coating, glass type and glass coatings can all impact the characteristics of the light emitted.
- The use of a photometer that matches the sensitivity of the human's eye-brain sensitivity will mask out any nonvisible energy.
- The display that is measured and calibrated with such a system will be less dependent on monitor type as a variable.

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Display calibration



DDL or P-Values

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LCD Specific Calibration Problems

- Need for reduced acceptance angle photometers to compensate for angular dependence of light emission
- Low refresh rate of screen causing flickering, photometer should collect light long enough between measurements to average the reading
- Separate data and screen refresh rates, potential for interference?
- Many high resolution LCDs actually are two or four LCDs binned together but sharing only one Look-Up Table, which makes calibration an average calibration and not specific

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LCD or not to LCD?

Tibor Duliskovich MD
7th of February, 2003

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LCD advantages over CRT (33 years old)

- Almost perfect MTF, but abrupt cut-off frequency
- Brighter, very bright white
- Perfect geometry, no distortions whatsoever
- Higher contrast ratio
- Uniform pixel size over the whole surface of LCD
- Fully digital signal pass, non-susceptible to electrical noise
- Less glare from ambient light
- Little burn-in over extended periods of time
- Is not emitting harmful radiation
- Small footprint, light-weight
- Less power-hungry
- Easy pivoting in portrait-landscape mode

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CRT advantages over LCD (108 years old)

- Uniform light distribution
- Little contrast reduction off-axis, no inversion artifacts
- Luminance non-uniformity <15% (LCDs 20-40%)
- No flicker for movie, high refresh rates, no mouse jumping
- No image sticking (it takes app. 1 minute for an dual-domain IPS LCD to relax from white to black!)
- Continuous gamma curve, closer to DICOM curve
- Black as dark as the glass (LCD light leakage causes black to be in the range of 1-2 cd/m², versus CRT 0.1-0.2 cd/m²)
- Surface not sensitive to scratches, do not require protective glass which further reduces performance of LCDs
- Easy calibration with wide acceptance angle photometers

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Acronyms

- AMLCD – Active Matrix Liquid Crystal Display
- CCFT – Cold Cathode Fluorescent Tube
- DVI – Digital Video Interface
- ELD – Electro-Luminescent Display
- FED – Field Emitter Display
- GPD – Gas-Plasma Display
- HDTV – High-Definition TeleVision
- Hz – Hertz (number of times per second)
- IPS – In-Plane Switching
- JND – Just Noticeable Differences
- LCD – Liquid Crystal Display

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Acronyms

- LUT – Look-Up Table
- LVDS – Low Voltage Differential Signaling
- NIT – Unit of luminance, equals to one candela/square meter
- Pixel – Picture Element
- SVGA – Super Video Graphics Array
- SXGA – Super Extended Graphics Adapter
- TFT – Thin Film Transistor
- TMDS – Transition Minimized Differential Signaling
- UXGA – Ultra Extended Graphics Adapter
- VGA – Video Graphics Array
- XGA – Extended Graphics Array

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- Dome technical articles: <http://www.dome.com/news/articles.html>, specifically this one <http://www.dome.com/support/pdf/caltqa/SPIE-2002.PDF>
- Digital Display Working Group – DVI standard v1.0
- Clinton Electronics CD-ROM
- DICOM Grayscale Standard Display Function by David Clunie

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End of presentation

Thank you very much for your attention !

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