STORcomm
The Clinical Image Management Company™

# 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

StorCOMM





## 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





## 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





## Conventional vs Digital Imaging

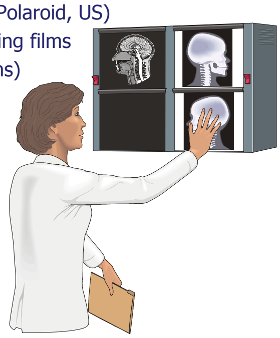
| | ***Conventional Imaging*** | ***Digital Imaging*** |
|---|---|---|
| ***Capture*** | Film in cassete | X-Ray detector, antenna, US transducer |
| ***Post-processing*** | Lupe on film, spot light | Software |
| ***Display*** | Film on light box | Monitor |
| ***Storage*** | Film in jacket | Optical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





## Types of radiological images

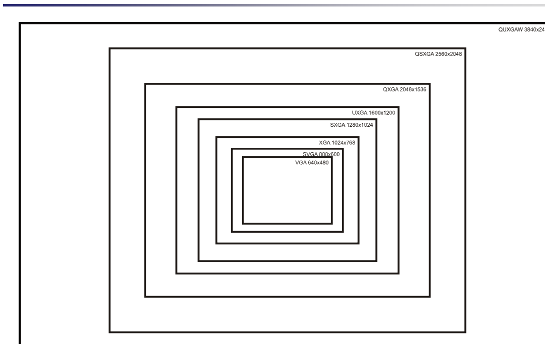
- Transparent (film) and opaque (Polaroid, US)
- Double and single emulsion coating films
- High and low speed films (screens)
- Different sizes and resolutions
- Color and BW images
- Motion images
- Only softcopy







## Display resolutions



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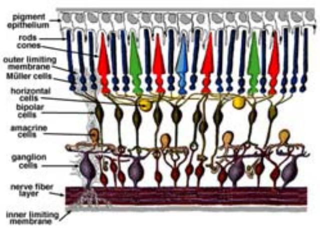
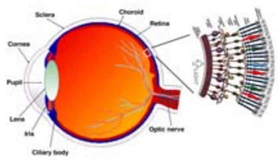
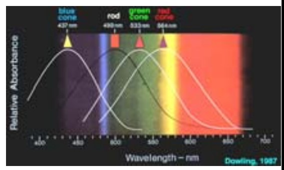
## Anatomy of human eye

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 fotpic vision (above 1-10 cd/m$^2$)
  - 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/m$^2$)
  - higher number on perifery of retina then in fovea centralis
  - signal from few hundred rods is convergated and summarized in a single nerve connection (signal-to-noise ratio improvement)
  - inferior spatial resolution and no color vision
  - great light sensitivity (0.75 x 10$^{-6}$ cd/m$^2$, 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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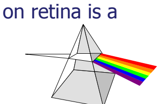
## Spatial resolution of human eye

- 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 µm, because of chromatic aberration and diffraction
- Diameter of a cone cell is 1.5 µm
- 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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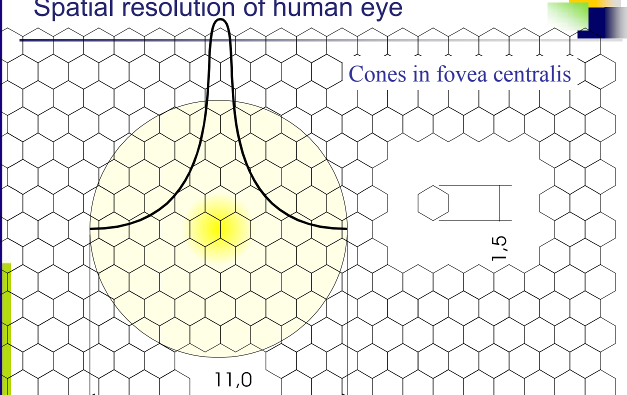
## Spatial resolution of human eye



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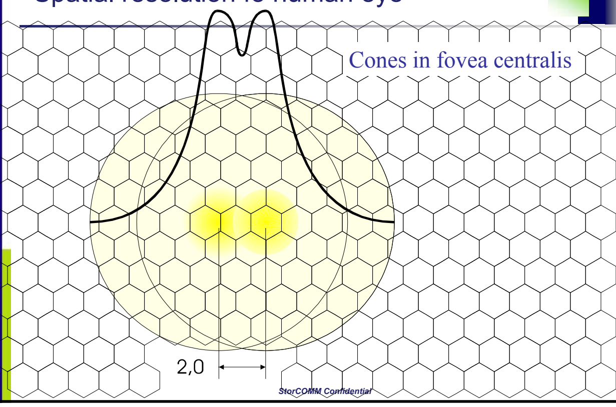
## Spatial resolution of human eye

- One can differentiate between two close light spots if there is at least 2 µm 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

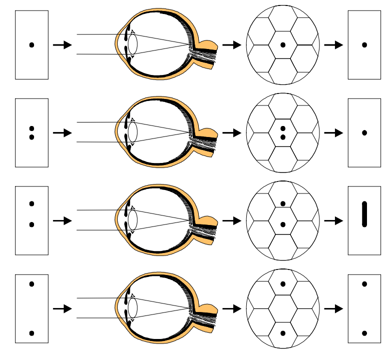
## Spatial resolution fo human eye








## Spatial resolution of human eye





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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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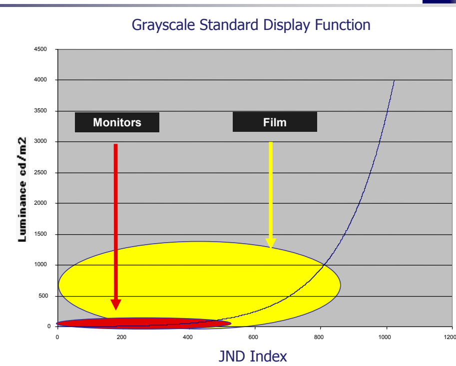
## Contrast sensitivity and DICOM

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

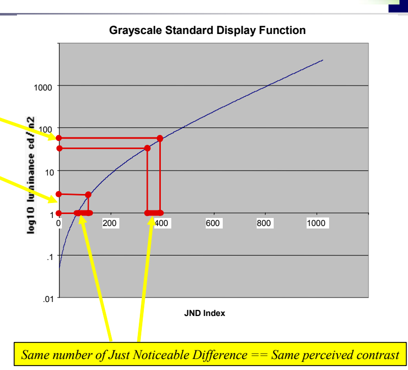







## Perceptual Linearization

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








## Physiology of human eye

- The reaction time of accomodation (focusing at different distances) is app. 0.3 sec and the time needed to accomodate is another 0.5 sec (monitor-keyboard-film)
- Ciliar 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 differenciate between colors with wavelength difference of as little as $10^{-7}$ mm
- 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

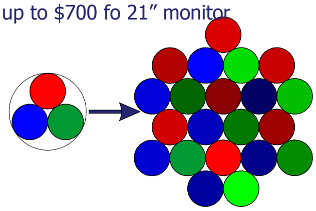
- Motion image (Ultrasound, Fluoroscopy, etc.):
  - low resolution
  - motion image
  - very high noise (low signal/noise ratio)
  - slow response of human eye will integrate the noise, perception is - good image quality (until you freeze one frame!)
- Still image (X-ray, CT, MRI, etc.):
  - high resolution
  - 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 fo 21" monitor

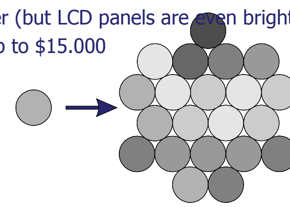






## Diagnostic quality monochrome monitor

- 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







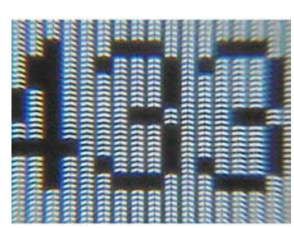
## Typical Medical Gray-Scale CRT specs

- 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 ($L_{dark}/L_{light}$) 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

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## 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 ($L_{dark}/L_{light}$) 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)



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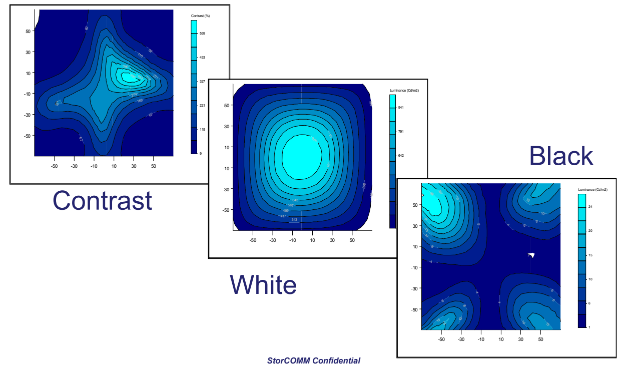
## Viewing angle dependencies on LCD



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## 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



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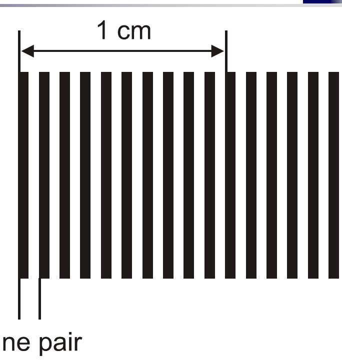
## Definition of resolution

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



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## 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.



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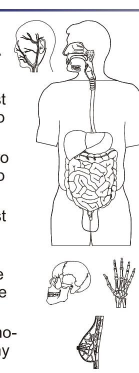
## Clinically required resolution



| | |
|---|---|
| DSA | 150 µm |
| Chest fluoro | 250 µm |
| Gastro fluoro | 250 µm |
| Chest film | 200 µm |
| Bone image | 100 µm |
| Mammo-graphy | 50-70 µm |

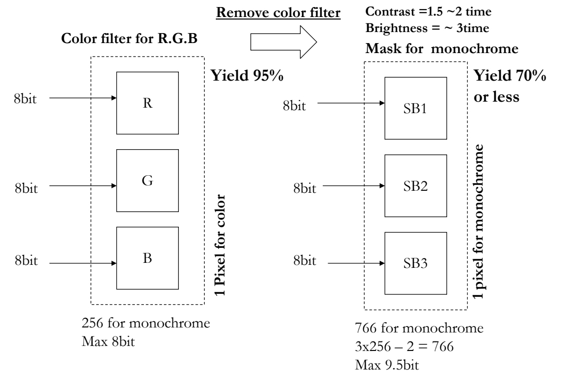
- Depends on type of exam
- According to ROC studies the diagnostic information is encoded in frequencies between 0 and 2 lp/mm !!!
- In case of mammography the requirements deviation is much higher than otherwise (image size up to 4600x6000 pixels 10 bit)

# STORCOMM
# Feb 7th '03

## 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/m2 | Anode power 600cd/m2 |
| 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

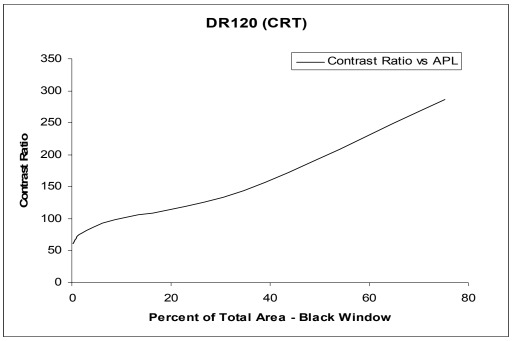
- 100% illuminate pixel defect
  >>> Specification
- White shading at the black back ground
  >>> Specification
- Variation of Color temperature
  >>> select LCD panel
- Gray shading at medium gray level
  >>> Specification



## 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) +2 bit – 3**
**Not enough for conformance to DICOM curve**
**Flickering problem for future LCD panel ( Tr/f < 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.

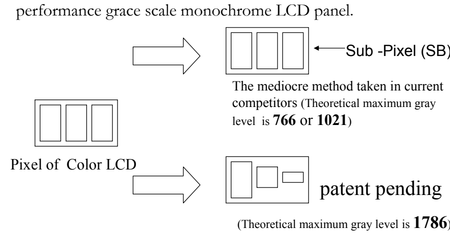
| Maker | DOME | BARCO | NationalDP | TOTOKU | Data-Ray |
|---|---|---|---|---|---|
| Theoretical gray level | 766 | 1021? | 766 | 1021 | 1786 |
| Cinema mode | yes | no? | yes | no | yes |

**Data Ray 's SHG Technology**



## Our unique technology for monochrome LCD

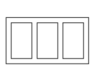
- A unique technology to change an ordinal color LCD panel to high performance grace scale monochrome LCD panel.



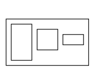



## Three kinds of methods

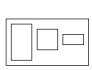
- Method-1,(ND filter)



- Method-2,(MASK filter)

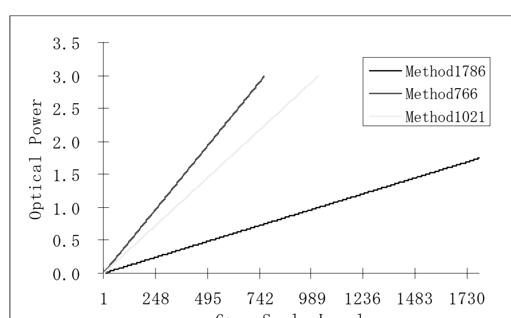


- Method-3,(TFT-metal)



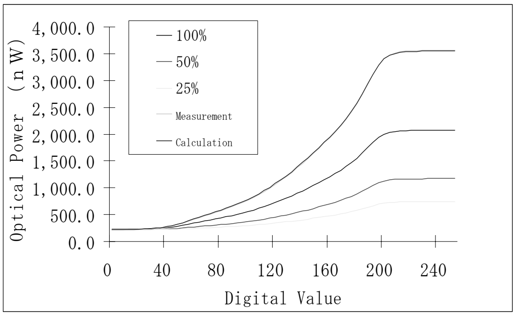


## Theoretical value



# Measurement result

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

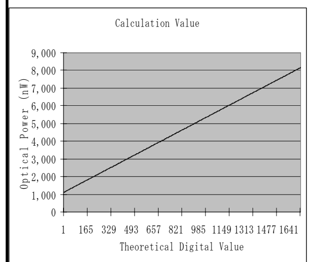


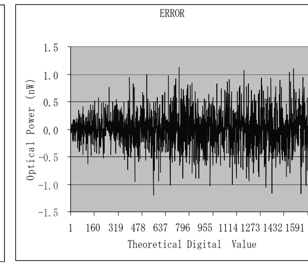



# Calculation result

- Theoretical value v.s. calculation value via basic experiment

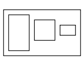
The synthesized value calculated from experiment result is just around ±1 error of about 1500 against theoretical value1786.



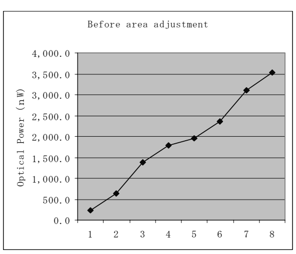


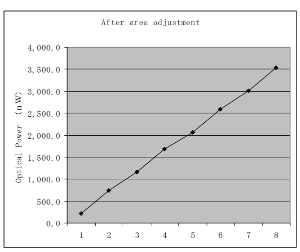

# Examination to light leaking



Method-2,(with MASK filter)

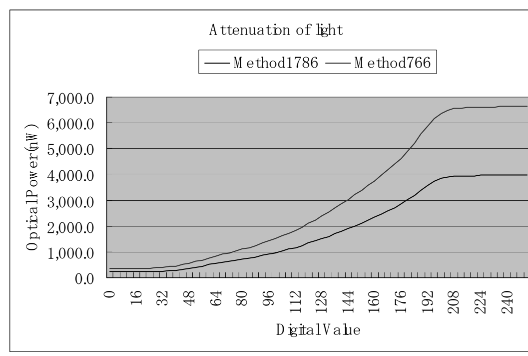
The measurement result



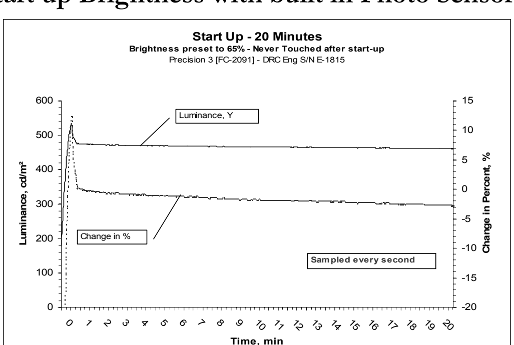



# Measurement value of attenuation



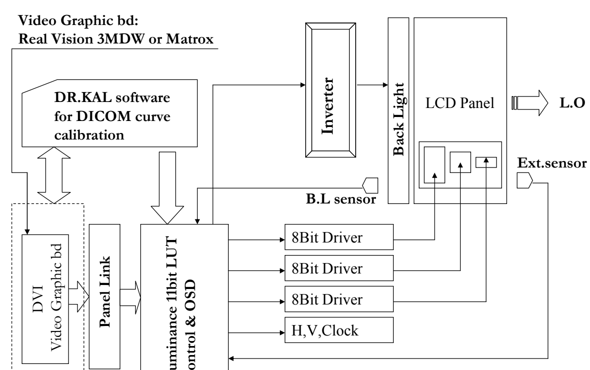



# Start up Brightness with built in Photo Sensor






# System block diagram with SHG system



# 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

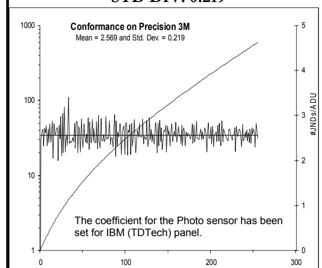
### Key factors for conformance

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)

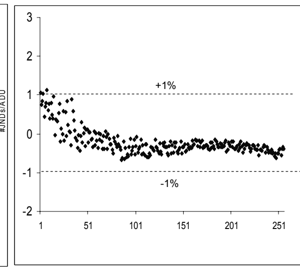


# DICOM conformance of Data Ray's System

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



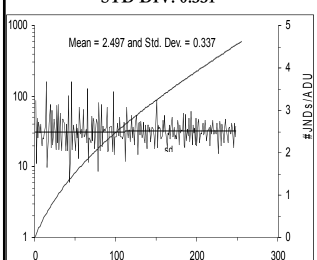

**PRECISION3's system**
**Sub-pixel + 1bit FRC(1531)**
**Error to DICOM curve**



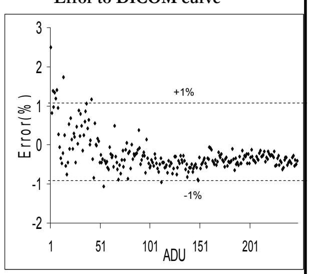



# The LCD gamma curve is not smooth

**STD DIV: 0.331**



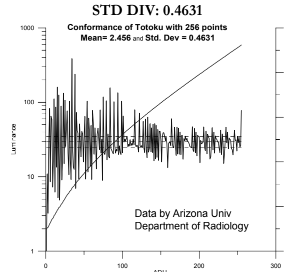

**Error to DICOM curve**



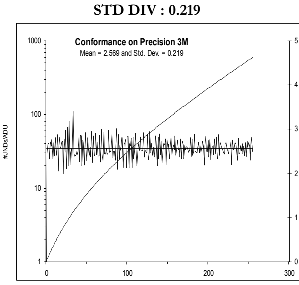



# The comparison of DICOM conformance

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



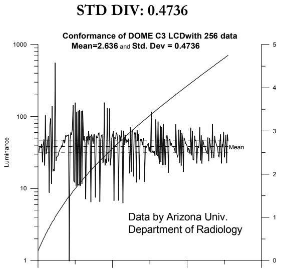

**PRECISION3's system**
**Data Ray Corp**
**STD DIV : 0.219**



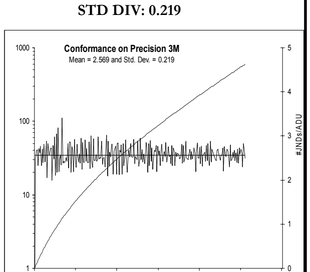



# DICOM conformance of the existing gray shade expansion technology

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




**PRECISION3's system**
**Data Ray Corp**
**STD DIV: 0.219**






# 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 yers for back light and 3 yers for electronics | 1 yr | ? | ? | ? | ? |

# 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

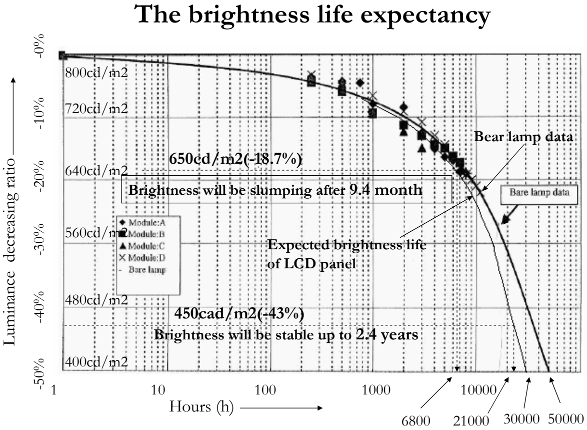
**450cd/m2 to 550cd/m2 should be recommended.**

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 after …...720cd/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**

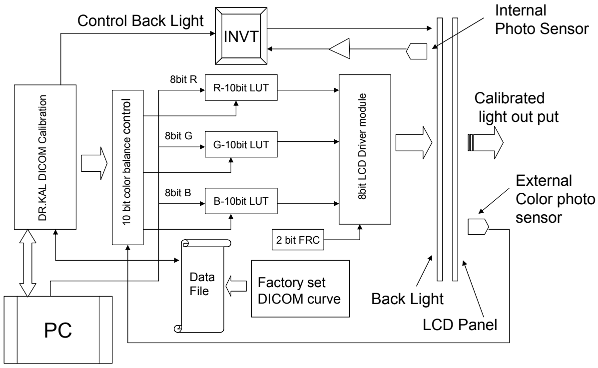


## Color LCD monitor for Medical Application

**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 Westminster CO80234

# Alternative technologies and LCD specific calibration problems

Tibor Duliskovich MD
7th of February, 2003







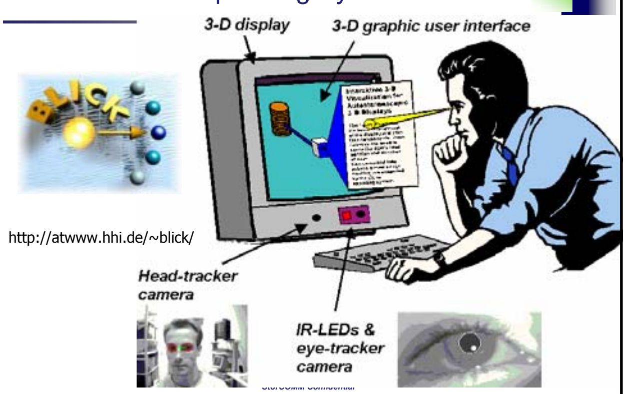
## Alternative Technologies

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





## Future? Visual Operating System




http://atwww.hhi.de/~blick/





## 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.





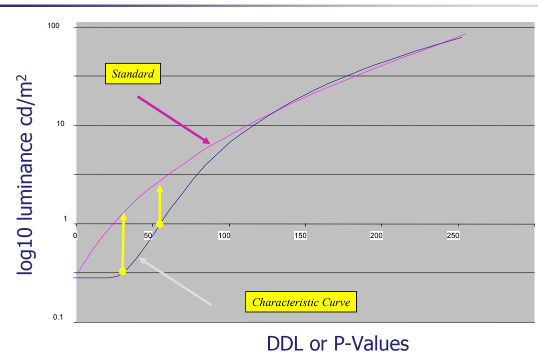
## Photometer

- 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.





## Display calibration



## 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 interferance?
- 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



# LCD or not to LCD?

Tibor Duliskovich MD
7th of February, 2003



## 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



## CRT advantages over LCD (108 years old)

- Uniform light distribution
- Little contrast reduction off-axis, no inversion artifacts
- Luminence 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/m$^2$, versus CRT 0.1-0.2 cd/m$^2$)
- Surface not sensitive to scratches, do not require protective glass which further reduces performance of LCDs
- Easy calibration with wide acceptance angle photometers



## 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 Noticable Differencies
- LCD – Liquid Crystal Display



## 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 Grpahics Array

Tibor Duliskovich, StorCOMM

## References


- AAPM Task Group 18: Assessment of Display Performance for Medical Imaging Systems - http://deckard.mc.duke.edu/~samei/tg18
- Brightness, Luminance, and Confusion by Charles P. Halsted http://www.resuba.com/wa3dsp/light/lumin.html
- Visual Experts http://www.visualexpert.com/Resources/perceptionhf.html
- 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




Tibor Duliskovich, StorCOMM

## End of presentation

Thank you very much for your attention !

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