Imaging Informatics

AAPM 2016

SAM Imaging Education Course

Standards Support for Color in Medical Imaging

- Photometric Standards
- Colorimetric Standards

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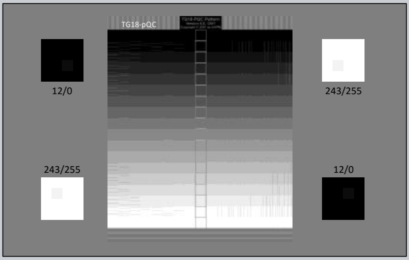
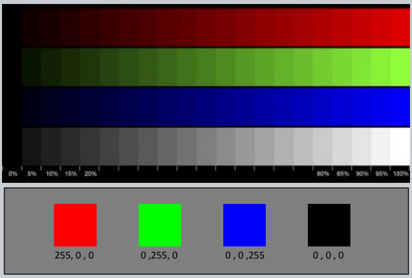
Display Quality Test Image



Display Quality Test Image



Photometric Standards

PHOTOMETRIC STANDARDS

Photometry is the science of the measurement of light, in terms of its perceived brightness to the human eye.
(Wikipedia)

VIII. E.2 – Photometric Units

Radiometric light units relate to the energy of photons (watts).

Photometric light units relate to the visibility of photons (lumens)

Radiant flux

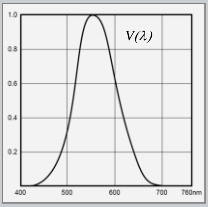
$$Q_e(\lambda) = E_\lambda N(\lambda)$$

$$\Phi_e(\lambda) = dQ_e(\lambda)/dt$$

Luminous flux

$$\Phi_e = k_m \int \Phi_e(\lambda) v(\lambda) d\lambda$$

$$k_m = 683 \text{ lumens/watt}$$



The sensitivity of the human eye is defined in terms of the lumens per watt as a function of wavelength.

VIII. E.2 – Photometric Units

Radiant/luminous intensity refers to the light flux emitted per steradian from a point source (*candle*).

Hamamatsu PMT Handbook

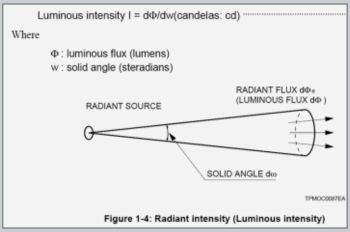


Figure 1-4: Radiant intensity (Luminous intensity)

Radiant/luminous intensity refers to the light flux emitted from an area on a surface per steradian.

(Note that it is adjusted by the 1/cosine of the viewing angle.)

Luminance, $L = (dI/ds)/\cos\theta$ candelas/m^2

Where

I: luminous intensity (candelas)

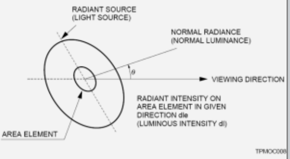
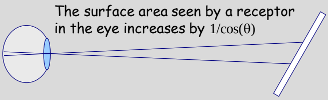


Figure 1-5: Radiant intensity (Luminous intensity)

Hamamatsu PMT Handbook

The luminance indicates how much luminous power will be detected by an eye looking at the surface from a particular angle of view.



Apparent brightness is independent of distance to the viewing surface;

- The surface area seen by a receptor in the eye increases with the square of the distance.
- The solid angle subtended by the eye lens decreases with the square of the distance.

Surfaces for which the luminous intensity, $d\Phi/d\omega$ (cd/sr) per unit area, ds, is proportional to the cosine of the emission angle are known as Lambertian emitters.

$$dI_{(\theta)}/ds = \left[(d\Phi/d\omega)_\theta / ds\right] = k\cos(\theta)$$

International Light Handbook

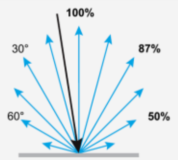


Fig. 6.5 Lambertian surface.

- Lambertian emitters are significant in that the luminance, and therefore the apparent brightness, is independent of viewing angle.

$$L_{(\theta)} = \left(dI_{(\theta)}/ds\right)/\cos(\theta) = k$$

- Lambertian emission results from diffusive surfaces such as projector screens, opal glass, and OLEDs (but not LCDs).

Assessment of display performance for medical imaging systems

- **Med. Phys. 32 .4., April 2005**
- **AAPM On-line Report 03, 2005**

AAPM On-line Report #03 from Task Group 18 (TG18) recommended methods for the photometric assessment of medical monitor luminance including:

- Luminance Response (LR)
- Maximum and Minimum Luminance (Lmax & Lmin)
- Ambient Luminance (Lamb)
- Uniformity & Noise

In 2009, the tg18 evaluation methods and terms for luminance and chromaticity were adopted in an international standard.

This is a preview - click here to buy the full publication

IEC 62563-1

Edition 1.0 2009-12

7.4 Quantitative evaluation methods
- 7.4.1 Basic LUMINANCE evaluation
- 7.4.2 Basic LUMINANCE evaluation without ambient light
- 7.4.3 LUMINANCE response evaluation
- 7.4.4 LUMINANCE evaluation of multiple displays
- 7.4.5 Chromaticity evaluation
- 7.4.6 Chromaticity evaluation of multiple displays
- 7.4.7 LUMINANCE uniformity evaluation
- 7.4.8 Viewing angle evaluation

TG18/IEC test methods have been widely adopted

- JESRA X-0093 : "Quality Assurance (QA) Guideline for Medical Imaging Display Systems" formulated by Japan Industries Association of Radiological Systems (JIRA).
- European Commission/EUREF: EC “European guidelines for quality assurance in breast cancer screening and diagnosis” and EUREF “Monitor QC Test Patterns
- DIN V 6868-57, PAS 1054: "Requirements and Testing of Digital Mammographic X-ray Equipment".

The recommendations have been adopted by suppliers of medical imaging monitors along with Quality Assurance software support often provided by photometers built into the device bezel.

ACR-AAPM-SIIM Electronic Imaging Guideline

J Digit Imaging (2013) 26:38–52
DOI 10.1007/s10278-012-9522-2

ACR–AAPM–SIIM Technical Standard for Electronic Practice of Medical Imaging

James T. Norweck · J. Anthony Seibert · Katherine P. Andriole · David A. Clunie · Bruce H. Curran · Michael J. Flynn · Elizabeth Krupinski · Ralph P. Lieto · Donald J. Peck · Tariq A. Mian

Published online: 20 September 2012

...
Equipment Specifications
- Acquisition
- Compression
- Transmission
- Display
  - [A] 1. Workstation Characteristics
  - 2. Display Characteristics
    - [C] a. Luminance response
    - [B] b. Pixel Pitch and Display Size

...

ACR Display 2 (a), JDI pg 44 - Luminance Response

Summary

Recommended Luminance Response Specifications

	Diagnostic	Other
L_{min}:	≥ 1.0 cd/m^2	≥ 0.8 cd/m^2
L_{max}:	≥ 350 cd/m^2	≥ 250 cd/m^2
Luminance ratio (LR)	~350 (≥ 250).	~350 (≥ 250).
Luminance response	GSDF	GSDF
GSDF tolerance	10%	20%
Pixel pitch	210 mm	~250 (<300) mm

- L_{amb} less than 1/4th of L_{min}.
- Diagonal size of 20-24 inches with 3:4 or 4:5 aspect
- D65 (6500 C) white point

Colorimetric Standards

COLORIMETRIC STANDARDS

Colorimetry is the science and technology used to quantify and describe physically the human color perception.
(Wikipedia, from Ohno2000)

International Commission on Illumination
Commission Internationale de l'Eclairage
Internationale Beleuchtungskommission

The CIE is a technical, scientific and cultural non-profit organization whose objectives include the development of standards, reports and other publications concerned with the science and technology of light and lighting.

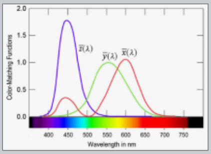
CIE 15:2004, Colorimetry, 3rd edition

http://www.cie.co.at/

CIE Central Bureau, Vienna, AUSTRIA

The CIE standard defines Tristimulus Values X, Y, Z as integrals of the spectral relative power $P(\lambda)$.

$$X = \int_0^\infty P(\lambda)\bar{x}(\lambda)\,\mathrm{d}\lambda,$$
$$Y = \int_0^\infty P(\lambda)\bar{y}(\lambda)\,\mathrm{d}\lambda,$$
$$Z = \int_0^\infty P(\lambda)\bar{z}(\lambda)\,\mathrm{d}\lambda.$$



The Luminance in given only by the Y tristimulus value

The color matching functions used to weight the power spectrum come from human visual experiments. They reflect the different response of the cones in the retina.

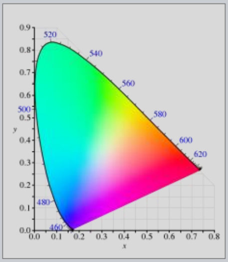
- CIE defines chromaticity as,

  $x = X / (X + Y + Z)$

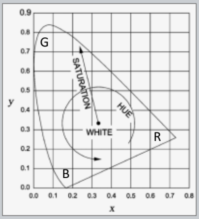
  $y = Y / (X + Y + Z)$

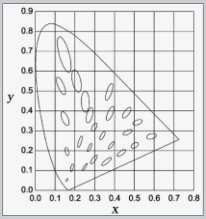
  $z = Z / (X + Y + Z)$

- Because $x + y + z = 0$, it suffices to quote only x,y.
- The diagram using the chromaticity coordinates is referred to as the CIE 1931 chromaticity diagram.



Colorimetric Standards





- Hue – direction from white
- Saturation – distance from white

McAdam ellipses (10x) represent equally noticeable color difference perceptions

Colorimetric Standards

CIE 1960:

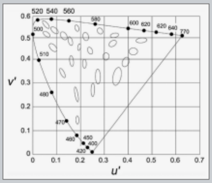
u,v uniform chromaticity

$$u = \frac{4X}{X + 15Y + 3Z} = \frac{4x}{-2x + 12y + 3},$$
$$v = \frac{6Y}{X + 15Y + 3Z} = \frac{6y}{-2x + 12y + 3},$$

CIE 1976:

u',v' improved uniformity

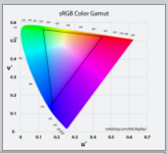
$$u' = u$$
$$v' = 1.5\, v$$



- McAdam ellipses (10x) represent equally noticeable color difference perceptions.
- The 1976 u',v' chromaticity coordinates are significantly more uniform with respect to the perception of color difference relative to the 1931 x,y coordinates.

Colorimetric Standards

- The 1976 u'v' chromaticity coordinates can be easily computed from measurements of the spectral power, $P(\lambda)$.
- As such, they are the preferred units for describing the white point and color coordinates of monitors.
- The color space of a monitor is typically defined by the u',v' coordinates of the white point and the R, G, and B points.
- sRGB is a common color space standard for display devices.



CIE has defined color spaces describing both luminance, L, and chromaticity which have further improvements in uniformity (L*u*v*, L*a*b*). Their complex dependence on luminance makes them inappropriate for monitor metrology.

Reference Document: sRGB: IEC 61966-2-1

- sRGB is a standard RGB color space created cooperatively by HP and Microsoft in 1996 for use on monitors, printers and the Internet.
- the sRGB gamma cannot be expressed as a single numerical value. The overall gamma is approximately 2.2, consisting of a linear (gamma 1.0) section near black, and a non-linear section elsewhere
- IEC 61966-2-1:1999 is the official specification of sRGB. It provides viewing environment, encoding, and colorimetric details.

IEC 61966-2-1
Colour Measurement and Management
in Multimedia Systems and Equipment
Part 2-1: Default RGB Colour Space – sRGB

http://en.wikipedia.org/wiki/SRGB

Reference Document: aRGB: Adobe RGB (1998)

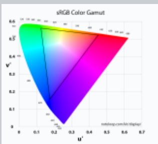
- The Adobe RGB color space is an RGB color space developed by Adobe Systems in 1998.
- It was designed to encompass most of the colors achievable on CMYK color printers, but by using RGB primary colors on a computer display.
- A gamma of 2.2 is assumed.
- The color space encompasses roughly 50% of the visible colors specified by the Lab color space, improving upon the gamut of the sRGB color space primarily in cyan-greens.

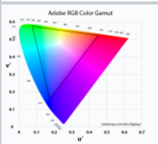
Adobe RGB (1998)
Color Image Encoding
Version 2005-05, May 2005

http://http://en.wikipedia.org/wiki/Adobe_RGB_color_space
http://www.adobe.com/digitalimag/pdfs/AdobeRGB1998.pdf

Color Spaces

- sRGB is the nominal color space for the majority of consumer and business monitors in use today. However, the actual color space may differ from the sRGB definition.
- aRGB is a more saturated color space (i.e. extended gamut) found in professional graphics monitors. These are often capable of being calibrated to either the sRGB or aRGB standards.

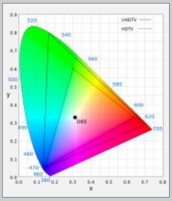




Color Spaces

Ultra HD

- 4k UHD – 3840 x 2160
- 8k UHD – 7680 x 4320
- 12 bits per color RGB
- Extended Color Gamut



UHDTV was officially approved in 2012 as a standard by the International Telecommunication Union (ITU), standardizing both 4K and 8K resolutions for the format in ITU-R Recommendation BT.2020

The Digital Cinema Initiative (DCI) also has a 4k with 4096 x 2160 array size. DCI 4k streams are compressed using JPEG2000.

UHD Monitors

UHD Professional Class Monitors

Manf.	Model	GSDF	Size (in)	Pitch, mm	Lmax, cd/m^2
• Eizo	FlexScan EV3237	√	31.5	.18	300
• NEC	PA322UHD	√	31.5	.18	350
• DELL	UP3214Q	√	31.5	.18	350

Current 4k UHD monitors use a Sharp IGZO IPS panel.

AAPM TG196: dRGB

AAPM Task Group No. 196

Requirements and methods for color displays in medicine.

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Mikio Hasegawa
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Peter Steven
Stan Swiderski
Gert Van Hoey

WORK IN PROGRESS

A medical RGB color space (dRGB) for color managed emissive displays

Report of AAPM Task Group 196

First reading -> Dec 2014

http://www.aapm.org/pubs/reports/

http://www.aapm.org/org/structure/default.asp?committee_code=TG196

Color spaces compared

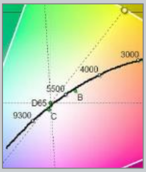
(1) IEC 62563 terminology

Specification (1)	sRGB	aRGB	ACR	dRGB
Luminance Response	~2.2 power function	2.199 power function	DICOM GSDF	DICOM GSDF
Color Gamut	HDTV based ITU-R BT.709-5	'Wide' (extended G)	-nd-	[*] (referenced)
L_{max} , cd/m^2	80	160 (125-200)	350/420/250	350 (250-450)
L_{min} , cd/m^2	-nd-	0.56	L_{max} / LR	L_{max} / LR
Luminance Ratio (LR)	-nd-	287.9 (230-400)	350 (> 250)	350 (300-400)
White Point	D65	D65	D65	D65
Gray tracking	-nd-	-nd-	-nd-	IEC MT51
Surround	20% refl. lx	Gray (D65, 2°) 20% L_{max}	-nd-	Gray (D65, >2°) 20% L_{max}
Ambient Illumination, lx	64 (D50)	32 (D65) (16-64)	20-40	-nd-
Veiling Glare	1.0%	accounted	-nd-	-nd-
L_{amb} , cd/m^2	-nd-	-nd-	$L_{amb} < {}^1/_4\ L_{min}$	$L_{amb} < [{}^1/_4 , {}^2/_3]\ L_{min}$

WHITE POINT

- CIE defines the coordinates of a white light similar to daylight.
- D65, x=0.31271, y=0.32902 (2° observer)
- D65 is the defined white point for sRGB, aRGB and dRGB (draft).
- Recent professional guidelines have recommended this as the white point for medical monitors.
  - ACR-AAPM-SIIM electronic imaging guidelines.
  - AAPM TG270 draft report.

- Specifying white point as D65 is preferred as opposed to the color temperature which is commonly used in monitor specifications.
- D65 is similar to a color temperature od 6500°.



GRAY TRACKING

- The white point of a monitor may vary with gray level, particularly for LCD devices.
- IEC 62563 ed 1, amendment 1 (2015) defines methods for grayscale chromaticity tracking using u',v' measures at 18 gray level.

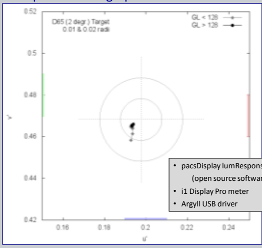
$$\Delta u'_i\, v'_i = \left((u_i' - u_{18}')^2 + (v_i' - v_{18}')^2 \right)^{1/2}$$

- Badano et. al., Med. Phys., 43, 4023 (2016) reports the results of AAPM TG196 evaluations of gray tracking using various colorimeters.

GRAY TRACKING

Evaluation of chromaticity vs gray level for a professional graphics monitor

- Maintaining monitor white point within 0.01 of D65 for all luminance values above 5 cd/m² is likely acceptable.
- Maintaining white point deviations within 0.005 would be desirable.
- Professional recommendations are currently being discussed in AAPM TG270.



- pacsDisplay lumResponse QC (open source software)
- i1 Display Pro meter
- Argyll USB driver

Color Display 2.0

Color presentation quality is important for:

- Digital Pathology
- Surgery
- Dermatology
- Opthamology
- Medical Photography
- …

In Radiology, consistent color presentation is desired for color scales used in NM, US, etc.

For diagnostic workstations, the white point of all monitors should be the same.

Color Display 2.0

Clinical Photography Examples

- Dermatology
- Reconstructive Surgery
- ER Abuse documentation
- Wound Management (Trauma Surgery)

Triathlon Bike Fall
XAVIER UNIVERSITY
WOUND CARE CASE STUDY

Dorsal Left Forearm Distal Wound

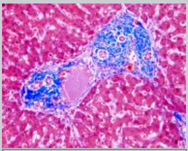
Day 1 (7/25/01) Day 2 (7/26/01) Day 3 (7/27/01)

Color Display 2.0

- Flash illumination with low ambient illuminance is used for consistent color.
- ICC color profiles can easily be generated for specific flash camera systems used with established firmware parameters

Color Display 2.0

Color images in medical specialties such as Ophthamology and Pathology use specialized equipment and analysis methods for which industry PACS solutions are available.



Liver - Masson Stain.

Paxcam image gallery

Retinal fundus image showing age-related macular degeneration.

National Eye Institute, NIH
Ref#: EDA22

Color Display 2.0

- Enterprise medical images come from many devices which can have different color spaces.
- Presentation of this images occurs on many display devices which can have different color spaces.
- A color management method is need to insure that images are presented with correctly rendered color.

The ICC

Adapted from *ICC* 2003

International Color Consortium

- An industry consortium
- Established in 1993 by eight industry vendors
- Now approximately 70 members
- Goal: Create, promote and encourage evolution of an open, vendor-neutral, cross-platform colour management system architecture and components

The ICC

Adapted from *ICC* 2003

International Color Consortium

Founders:

Adobe Systems Incorporated
Agfa-Gevaert N.V.
Apple Computer, Inc.
Eastman Kodak Company
FOGRA-Institute (Honorary)
Microsoft Corporation
Silicon Graphics Inc.
Sun Microsystems, Inc.
Taligent, Inc.

The ICC

- ICC develops and promotes a standard colour profile specification (ICC Profile).
- Available as PDF at
  www.color.org
- The current version of the ICC Profile Specification is 4.2.0.0 (ICC.1:2004-10).
- This version is essentially the same as ISO 15076-1:2005, which is available from ISO.
- A next generation platform, iccMAX, in currently being introduced.

ICC color management

Adapted from *ICC* 2003

- For each device, there is a transformation from the device to a standard colour space.
- Transformations have source-to-standard colour space or destination-to-standard colour space information.

ICC color management

Adapted from *ICC* 2003

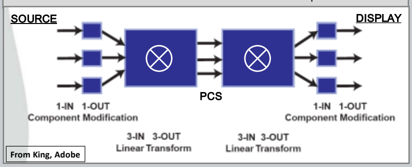
- The transforms from device to standard colour space are embedded in the ICC profile.
- The standard colour space is called PCS (profile connection space).

Color Display 2.0

International Color Consortium

Color managed presentation of an image using ICC input & output profiles

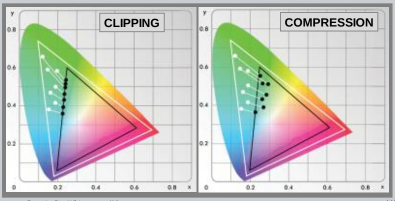
- Linearization and matrix transformation of the source camera data to PCS.
- Matrix transformation of the PCS values and non-linear output modification..



PCS – Profile Connection Space (nCIE XYZ)

ICC Four Rendering Intents

When the camera color gamut is larger than the display color gamut, some compromise must be made in the presentation.



From LaCie, Whitepaper #4

ICC Four Rendering Intents

Adapted from ICC 2003

Perceptual

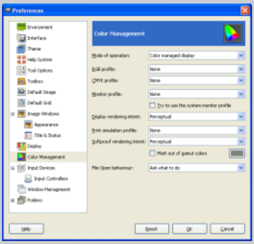
the full gamut of the image is compressed or expanded to fill the gamut of the destination device. Grey balance is usually preserved, but colorimetric accuracy might not be.

Saturation

the saturation of the pixels in the image is preserved, perhaps at the expense of accuracy in hue and lightness.

Color Managed Applications

- An application implementing full color management will use both the source device (camera) profile and the display device (monitor) profile.
- Additionally, the user will specify the rendering intent.
- Some applications will also specify a working space allowing the appearance of an image on an output device to be simulated.
- Examples include:
  - Adobe Photoshop
  - Gimp
  - Firefox 3
  - Fast Image Viewer
  - MS Image Viewer

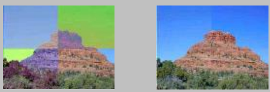


Color Management Window from GIMP

Color Managed Applications

- Source profiles are typically embedded in an image header using digital camera acquisition application.
- The ICC standard defines how to embed an ICC profile into JPEG, GIF and TIFF headers.
- DICOM defines how to embed an ICC profile into a color image object.

ICC Color Management Browser Test, www.color.org



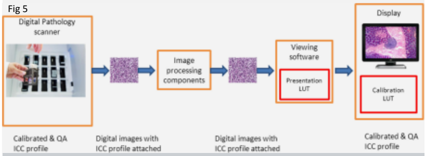
No profile support | Full profile support

Color Display 2.0

In 2013, after the ICC/FDA Color Summit, the ICC formed a Medical Imaging Working Group (MIWG, www.color.org)

- Badano et. al., Consistency and Standardization of Color in Medical Imaging: a Consensus Report, J Digit Imaging, published on line 09-July-2014.
- *"This article summarizes the consensus reached at the Summit on Color in Medical Imaging held at the Food and Drug Administration (FDA) on May 8–9, 2013, co-sponsored by the FDA and ICC (International Color Consortium)."*

Fig 5



Color Display 2.0

AAPM TG196 (color display):

"A DICOM RGB color space (dRGB)" (under development)

Use of dRGB with color managed application

1. Clinical color image presented on a Radiology DICOM workstation.

Image.jpg
- color
- [*]RGB CS

[*]RGB.icc →

Health System App.
- Patient records

dRGB-[*].icc →

Primary Display
- GSDF grayscale
- dRGB-[*] Calibr

2. DICOM Radiology image presented on a clinical workstation.

Image.dcm
- GSDF intent
- RGB (no CS)

dRGB-[*].icc →

Health System App.
- Patient records

[*]RGB.icc →

Secondary Display
- Default condition
- [*]RGB CS

→⊗→⊗→ Denotes a color managed module Using source and display profiles

CS – Color Space
CMS – ICC Color Management (full)

Questions?

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