Medical Imaging Working Group meeting

HP Indigo
Sderot Avats 24
Kiryat Gat 82000
Israel
18 February 2019

Craig Revie, MIWG chair, opened the meeting at 09:45. Following self-introductions, the items discussed were as follows:

1. Update on skin colour database and related applications
2. Medical imaging projects at NTNU
3. DICOM update
4. Work being done in AAPM TG322

1. Skin colour database

Dr Kaida Xiao gave an update on work on skin colour measurement and applications [see attached]. This work was now based at Leeds University in the UK.

He summarised the wide range of applications for skin colour and associated requirements. He observed that there is strong visual sensitivity to skin colour, one reason being that the chromophores correspond to the peak wavelengths of human visual sensitivity. In his work skin colour was characterised as reflectance, independently of the incident illumination. Point measurements were taken using telespectroradiometer (TSR) and spectrophotometer (SPM), while DSC and multi-spectral cameras were used for image-based measurements. Illumination was diffuse, using D65-simulating fluorescent lamps.

Dr Xiao summarised the CIE TC1-92 skin colour database. Factors which affected results included field size and (for contact instruments) pressure, and he had investigated the effect of exercise and season. Measurement area is affected by the aperture on a SPM and the relative position of the TSR. Results were shown for repeatability and for colour gamut. Clustering of the data suggested a possible future representative skin colour chart.

He described the use of PCA to derive components in order to transform camera RGB to reflectance. He noted that existing methods of spectral reconstruction do not preserve spectral peaks. Tom Lianza suggested a mix of spectral and metameric matching was needed, and that an angular subtense of less than 2 degrees should be used. The meeting also discussed skin colour difference and acceptability tolerances.

Dr Xiao reported that TC1-92 will close this year, but the members wish to establish a CIE research forum. In establishing the TC it had been assumed that a strict measurement protocol was needed, but it had been learnt that the metrology is application-dependent.

2. Medical imaging projects at NTNU

Phil Green presented a summary of work undertaken by students on the Colour in Medical Imaging course at NTNU [see attached]. Some of the work may be published at conferences such as SPIE Medical Imaging.

3 DICOM update

Craig Revie presented an update on DICOM on behalf of Dr David Clunie [see attached].

DICOM is a common standard for medical imaging, and the extension of DICOM to include ICC profiles was an activity in MIWG. The profile can be defined using EXIF metadata.

The meeting discussed the possibility of using XMP metadata format, but it was confirmed that EXIF was adequate. DNG (camera raw) images were also discussed, and it was felt that a case would need to be made for this.

DICOM holds regular interoperability sessions (‘Connectathons’), where some vendors are using ICC profiles in whole-slide imaging (WSI). Additionally some medical imaging vendors are demonstrating the use of colour management in their products, leading to wider take-up. Auto-analysis of images is being used in triage of WSI images.

4. Work being done in AAPM TG322

Craig Revie presented a summary of CSDF colour calibration currently being standardized in AAPM [see attached]. In medical imaging there are different rendering objectives for grayscale, pseudo-colour and true-colour (the latter being either colorimetric or appearance). The grayscale GSDF standard is based on contrast sensitivity work by Barten, and AAPM 196 specifies how to calibrate a colour display to match the GSDF scale.

CSDF extends GSDF to colour, based on uniform colour difference spacing (CIEDE2000) between steps in the primary and secondary scales (the gamut interior is undefined, but should be smooth). The Barco method has been published but is not required by the AAPM standard. The same data can be used to do CSDF calibration and the ICC profile.

Eizo would like to see support for legacy sRGB. One problem with CSDF is a lack of support, tools etc.

It was observed that GSDF is based in JNDs in neutrals, while CSDF is defined in CIEDE2000, and the specification indicates that there should be a smooth transition between these but does not define how to achieve this.

There being no other business, the meeting closed at 11:00.

ICC Medical Imaging Working Group

Tel Aviv

18th February 2019 (09:30-10:30)

ICC MIWG Working group meeting

February 2019

• Introductions	
• Medical imaging projects at NTNU	Phil Green
• Update on skin colour database and related applications	Kaida Xiao
• DICOM update	[David Clunie]
• Work being done in AAPM TG322	Craig Revie

International Color Consortium

DICOM update from David Clunie

I won't be able to attend the meeting in Tel Aviv or dial in, but I would like to update you on the status of the mapping of EXIF tags to DICOM attributes.

This has been accepted by the DICOM Standards Committee and is now part of the released standard. See:

http://dicom.nema.org/medical/dicom/current/output/chtml/part17/chapter_NNNN.html

http://dicom.nema.org/medical/dicom/current/output/chtml/part03/sect_C.8.12.10.html

http://dicom.nema.org/medical/dicom/current/output/chtml/part03/sect_C.8.12.11.html

http://dicom.nema.org/medical/dicom/current/output/chtml/part03/sect_C.8.12.12.html

The other item of work for DICOM that was suggested was the encoding of DNG format images; if anybody is still interested in that, let me know.

We are continuing to hold DICOM whole slide imaging Connectathons to demonstrate the use of DICOM encoding of WSI images, and several vendors have demonstrated the use of ICC profiles encoded in DICOM for color consistency at those events. The next event will be at ECDP in Warwick in April.

Though it is not related to the matter of color, one complaint we heard in the past from photographers using DICOM for dermatology is a lack of sufficiently specific surface anatomy codes to identify the site of the image. This has been rectified too. See: http://dicom.nema.org/medical/dicom/current/output/chtml/part16/sect_CID_4029.html

The Norwegian
Colour and Visual Computing
Laboratory

NTNU

Colour in Medical Imaging

Coursework projects Fall 2018

The Norwegian Colour and Visual Computing Laboratory
Faculty of Computer Science and Media Technology
Norwegian University of Science and Technology
Gjøvik, Norway
http://www.colourlab.no

Colour Science and Industry

- 2-year Master degree
- EU Erasmus+ joint Master degree offered by 4 European universities + 15 industrial partners
- Consortium partners include Barbieri, FFEI, HP, Technicolor
- https://master-colorscience.eu/cosi-master-degree/
- Applied Colour Science semester in Norway

Colour in Medical Imaging

- 7.5 ECTS course
- Students undertake a coursework project on a medical imaging topic
- Co-supervision by Prof. Ruud Verdaasdonk, Amsterdam Free University Hospital
- Most projects involve an experimental set-up based on a novel imaging application and low-cost imaging devices
- Steps typically include building a suitable phantom, setting up imaging system and recoding and analyzing results

Olexi Siderov, GAN based smoke removal in laparoscopic images

Thitinun Pengying, Effect of cooling and heating products on skin temperature

Yen-Ting Lee, Real-time heart rate monitoring using a HD webcam

Piotr Pawelczyk, Real-time airflow imaging and quantification using Background Schlieren Imaging

Majid Ansari-Asl, On the Evaluation of 3D Scanning Mobile Apps

Tanzima Habib, A study on substantivity and durability of Suncreens guarding from UVA

Aldo Barba, Implementing the Colour Standard Display Function (CSDF) using Colour Ramps

Daria Kruzhinskaia, Real-time video enhancement for detection of anomalies on the skin

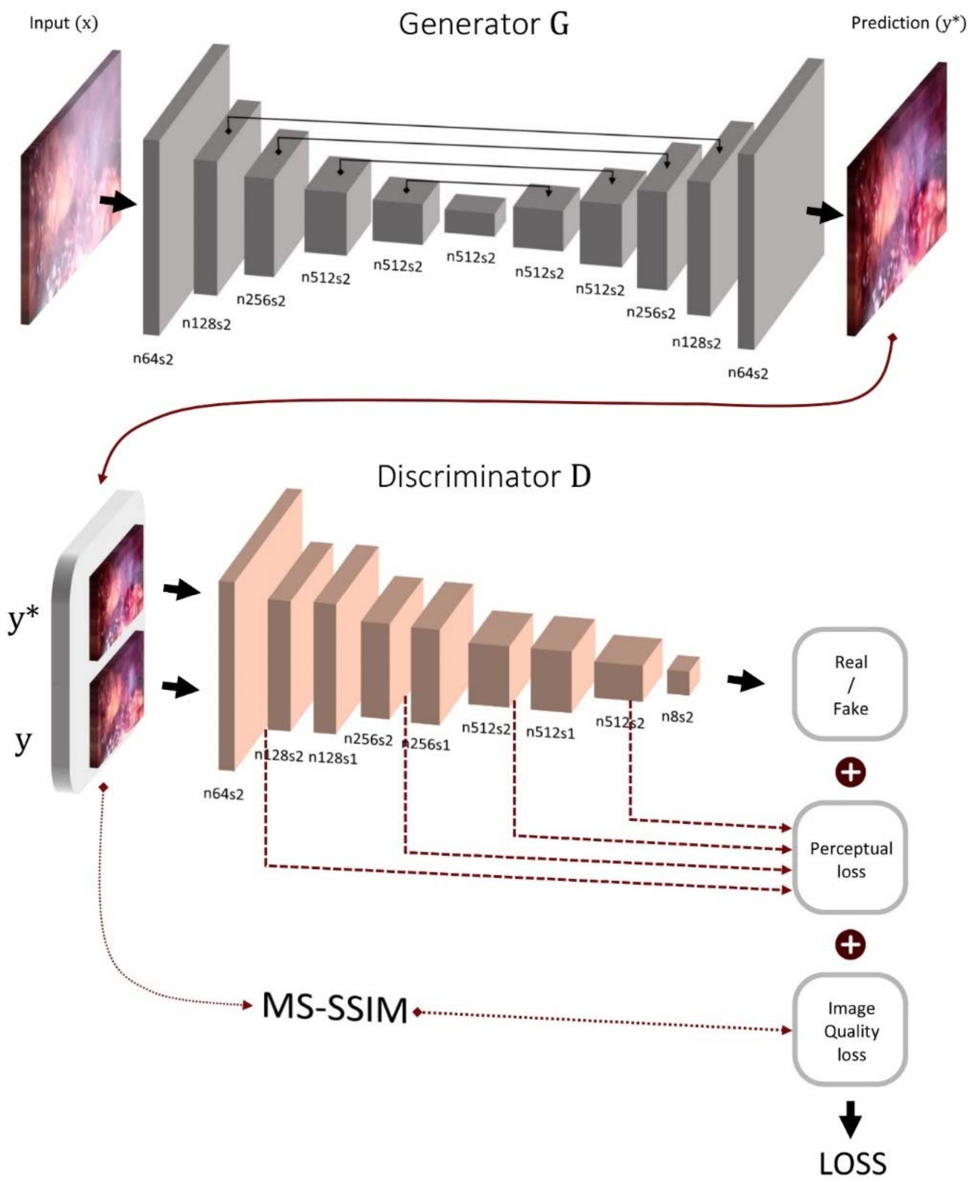
Altynay Kadyrova, Comparative Analysis of Skin Reflectance between African and Caucasian Ethnicities

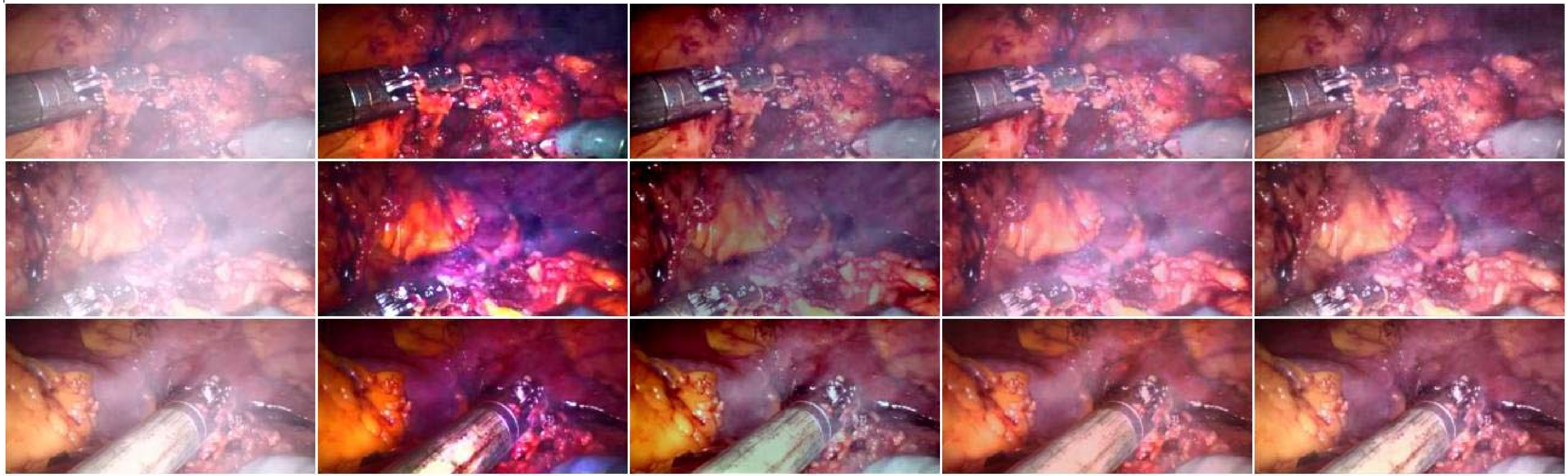
The quality of an images obtained during laparoscopic surgery can be severely degraded by smoke

It affects visibility of organs for clinicians and worsens the performance of digital navigational systems

Deep learning GAN paradigm was used to train a model on the synthetic data

The novel architecture based on Perceptual Adversarial Network (PAN) was developed using additional SSIM loss functions.





(a) (b) (c) (d) (e)

Obtained results demonstrate that proposed method efficiently removes smoke as well as preserves perceptually sufficient image quality

	CIEDE2000		RMSE	
	mean	std	mean	std
RDCP [8]	12.9	1.32	35.0	4.55
DCP [11]	11.5	2.13	40.6	6.98
VAR [5]	10.8	2.18	38.1	8.00
EVID [29]	7.41	1.40	24.2	4.81
Proposed	3.89	1.15	14.6	4.71

A study on substantivity and durability of Suncreens guarding from UVA

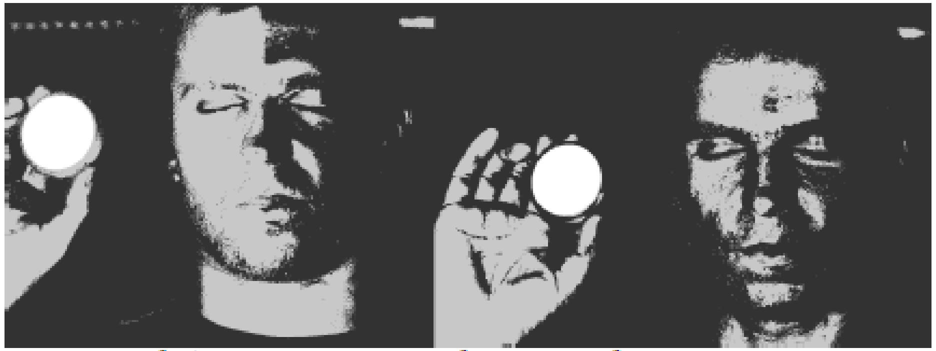
(Specialization in Medical Imaging Project)

- SPF is defined as the ratio of the minimal dose of ultra violet energy that causes erythema (redness) on skin protected with sunscreen (2mg/cm2) to the dose of UVB required to produce the same amount of erythema on unprotected skin.
- Substantivity is a measure of resistance of a sunscreen to being washed off by water (during swimming, sweating etc.)
- Durability is another measure of a sunscreen to being able to withstand wear over time and normal activities. it is well established that human skin maintains SPF level of a sunscreen over 8 hours of application if not physically wiped

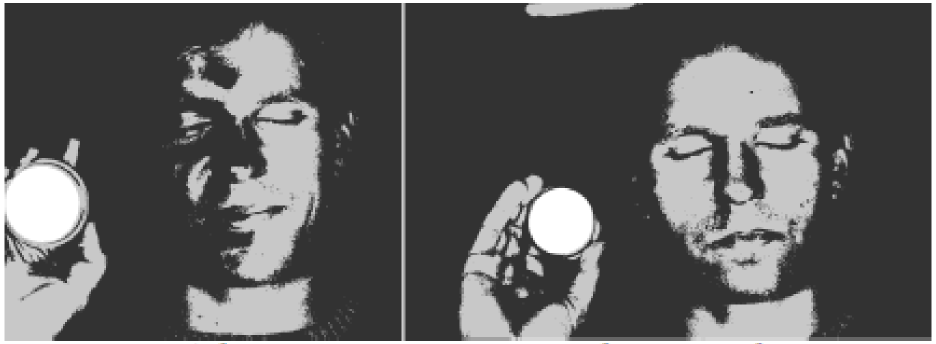
Three Methods:

- UV transmission readings were taken applying sunscreen on surgical tapes (320nm -400nm).
- Leather patches were used to simulate human skin and reflection readings were taken for each sunscreen applied on the leather patches (320nm -400nm).
- UV images were taken for in vivo test where only one subject of Fitzpatrick skin type III was chosen to apply the sunscreen on and perform some physical activities. K-means was applied on the UV images.
- UV light at 365nm was used as source light

K-means Segmentation applied on UV images



Durability segmentation before and after exercise for K50(left) and C25(right).



Substantivity segmentation before and after swimming for C25 (right) and K50(left).

Results

- With respect to durability, chemical sunscreens with three different UVA protection ingredients resist heavy sweat and physical wiping compared to physical sunscreen.
- Sunscreen wears out from the forehead and the cheek.
- In the case of substantivity none of the sunscreens could withstand water exposure for 1 hour. They were labelled high water resistance and are not expected to work for more than 1 hour of water exposure.
- The transmission measurements using UV spectrometer is the most reliable way to measure UV protection of sunscreen among the three methods used.

IMT4301
Real-time heart rate monitoring using a HD webcam

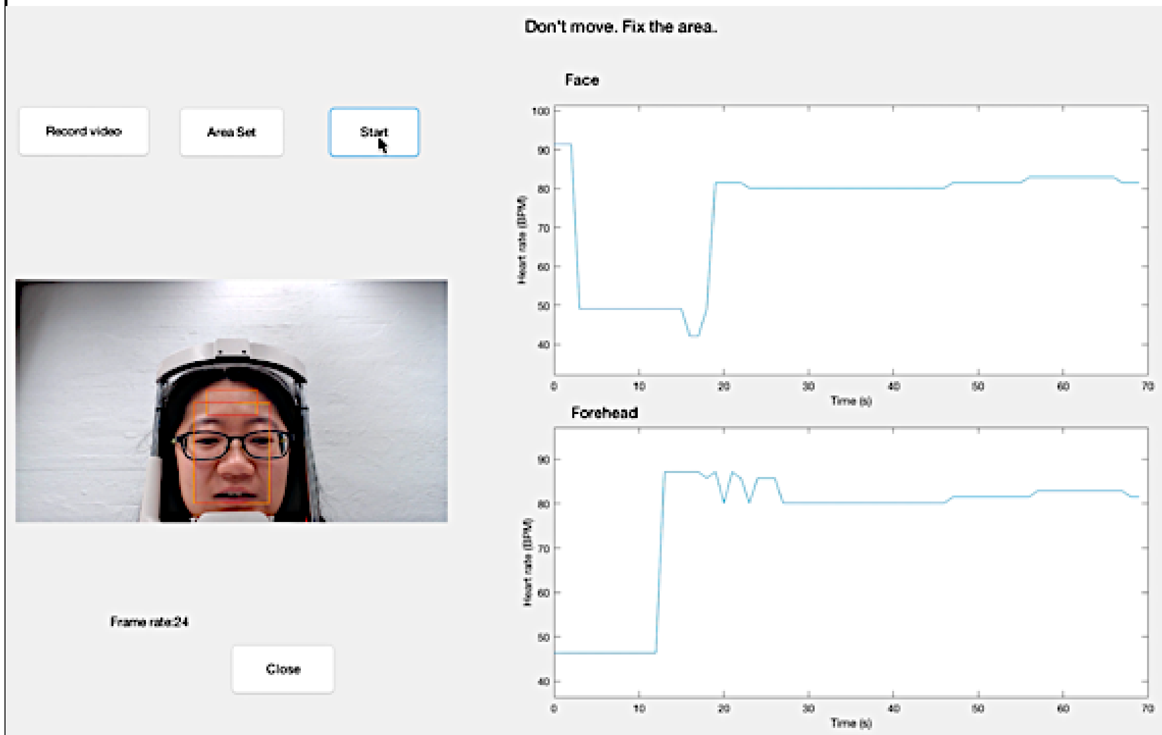
Yen-Ting Lee

Introduction

- Measuring heart rate (HR) in real time by using a HD webcam which is non-contact device with automatic detection of facial skin and forehead in the video frames.
- The ground truth HR is measured with a finger pulse oximeter at the same time.
- There are three types of experiments in this project
  - (1) Detecting the forehead and face and the participants cannot move.
  - (2) Detecting and tracking the face and forehead of the subject during the measurement (the participants can move).
  - (3) The participants are asked to do exercise to increase HR and then measure HR during the cool down period.

Results

- Detecting the forehead and face and the participants cannot move.



Ground truth: 86 bmp

- The HR is unsteady in the beginning and after 20 seconds, it is constant.

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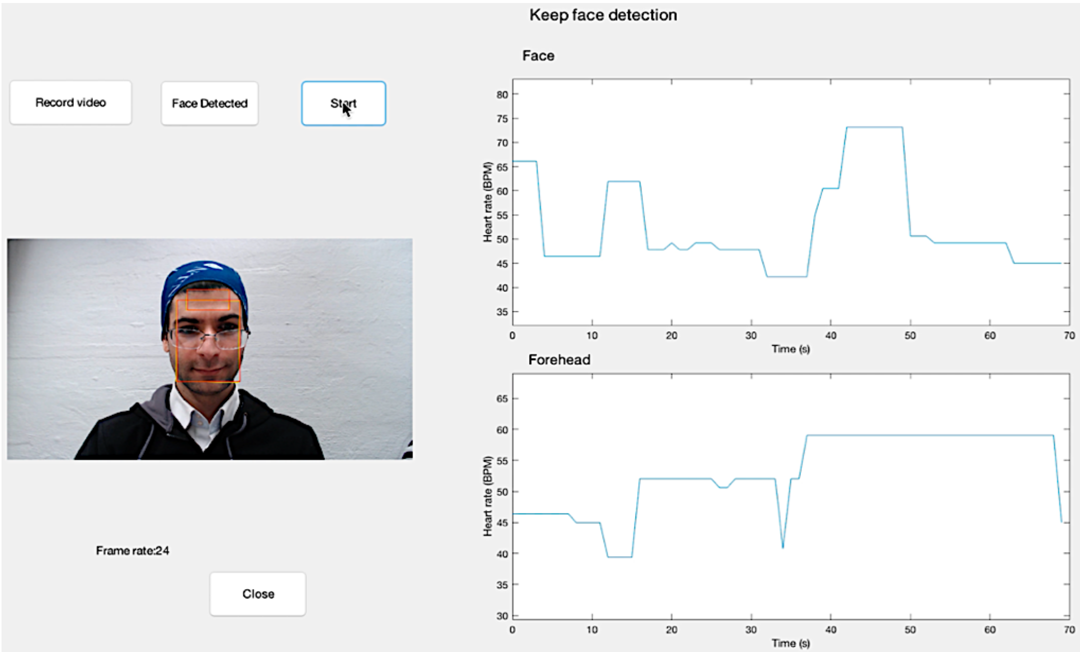
Results

- Detecting and tracking the face and forehead of the subject during the measurement (the participants can move).

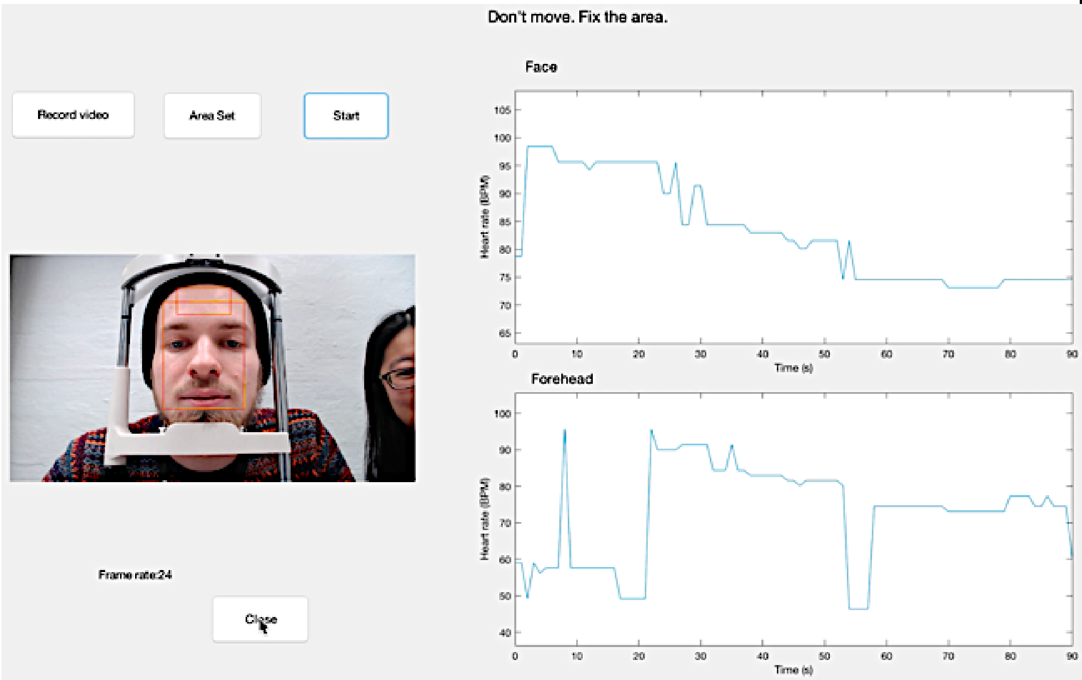


Ground truth: 67 bmp

- The face and forehead tracking does not perform well while the participant is moving.
- When the participants change the position of head, the webcam may perceive the various color due to the angle of reflection from the light .

Results

- The participants are asked to do exercise to increase HR (above 120 bmp) and then measure HR during the cool down period.



Ground truth: 97-80 bmp

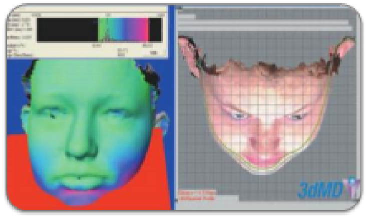
- Overall, only 2 of 9 participants got reasonable HR.
- The participants were still breathing heavily after exercise instead of fixing the head.
- It also depends on the skin color since people who have dark skin are more difficult to detect the variation of skin tone after doing exercise.

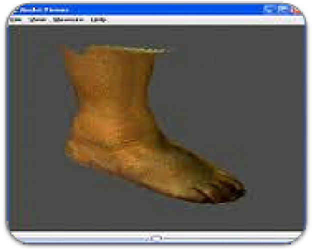
On the Evaluation of iPhone 3D Scanning Mobile Apps: Introduction

- Photos are for many medical specialties like dermatology and plastic/esthetic surgery still the 'golden' standard
- 3D scanners make scans of body parts with high accuracy.

Diagnostics

- Growth defects
- Abdominal shape
- Lung volume
- Melanomas



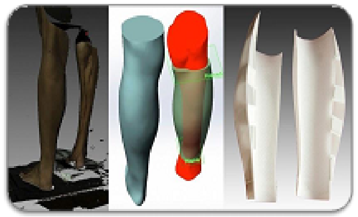


Monitoring

- Fitness and diet
- Obesity
- Diabetes

Treatment

- Scoliosis
- Prosthetics
- Burns
- Facial reconstruction



Source: Prof. Verdaasdonk's presentation at SPIE

Problem Statement:

- High-end scanners are expensive and need trained users.
- New iPhones have fully functional, cheap and easy to use 3D scanning apps.

Objective:

- Testing the accuracy of smart phone based 3D scanning in medical applications (face scanning).

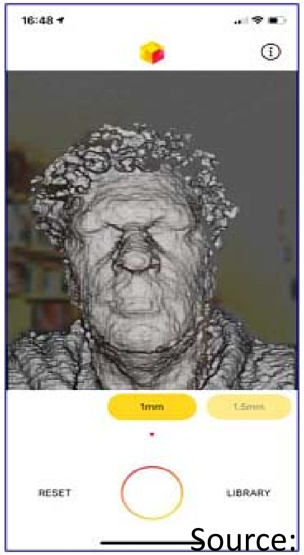
High-end scanner

Artec Spider
€ 16.000

Vectra M3
€ 60.000

iPhone Apps

STL Maker
- price $15
- export STL only
- resol 1mm



Bellus 3D
- price $ 25 yearly
- export STL, OBJ PLY (color)
- resol 0.5mm
- Faces only !!

Source: Prof. Verdaasdonk's presentation at SPIE

Experiment

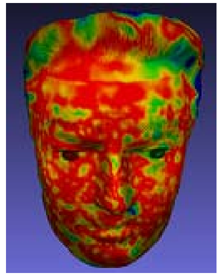
- 3 face phantoms and 2 real faces
- 2 mobile apps: Bllus3D & STL Maker
- 2 iPhone models: iPhone X & iPhone XS
- 3 repetition for each scan
- Fixed scanning distance, time, and illumination
- Mesh analysis in meshLab software
- AICON smartScan as ground truth scanner

Fig. 2. The main setup for model scanning.

Fig. 3. A setup in presence of a ColorChecker.

Fig. 1. AICON SmartScan.

Results



- Reproducibility of the mobile apps is approved.

- Bllus3D vs. STL Maker mobile apps:
  - ➢ Bigger meshes for STL Maker than Bllus3D
  - ➢ Higher accuracy for STL Maker around hairs
  - ➢ Higher accuracy for Bllus3D in face and around

  - ➢ Scans from 2 apps don’t match exactly

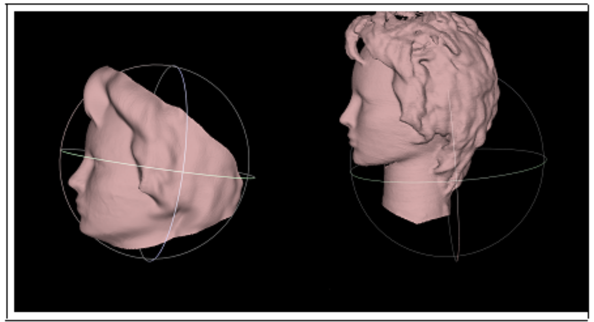
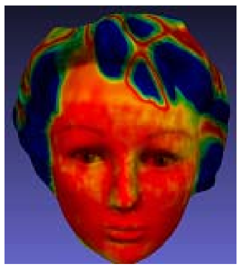


Fig. 16. Bellus3D(Left) vs. STL Maker(Right)

- iPhone X vs. iPhone XS:
  - ➢ Scans completely match



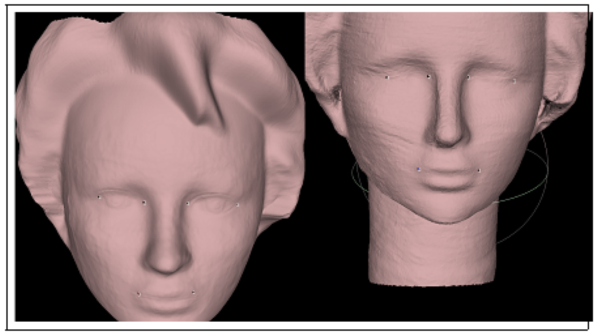


Fig. 17. Bellus3D(Left) vs. STL Maker(Right)

- Apps vs. high-end scanner: ongoing

Implementing the Colour Standard Display Function using Colour Ramps

- Implement CSDF on a monitor that is already calibrated to GSDF: linearizing the chrominance signal while maintaining the grayscale linearization within standard tolerances

- Method:
  - Calibrate display to GSDF
  - Measure ramps of RGB primaries from / to white and black
  - Linearize measured ramps by linear interpolation using ΔE2000 as metric of uniformity
  - Visually match measured and linearized ramps using HLS tools provided by colour correction software
  - Build a 3D lut that implements the HLS transformations

Implementing the Colour Standard Display Function using Colour Ramps

- Results
  - After CSDF calibration, GSDF was not affected and remained within tolerances
  - Gamut of display was maintained
  - Chrominance was linearized but did not stay within tolerances specified by ICC proposed metric
  - Contrast and luminance of the display were reduced about 5%
  - Visible colour shifts in blue region seen in test pattern proposed by Barco.

- Some projects published at SPIE Medical Imaging, 2019
- Projects for 2019 cohort in development – collaborators welcome

School of Design

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Skin colour measurement and applications

Kaida Xiao

Human Skin Colour

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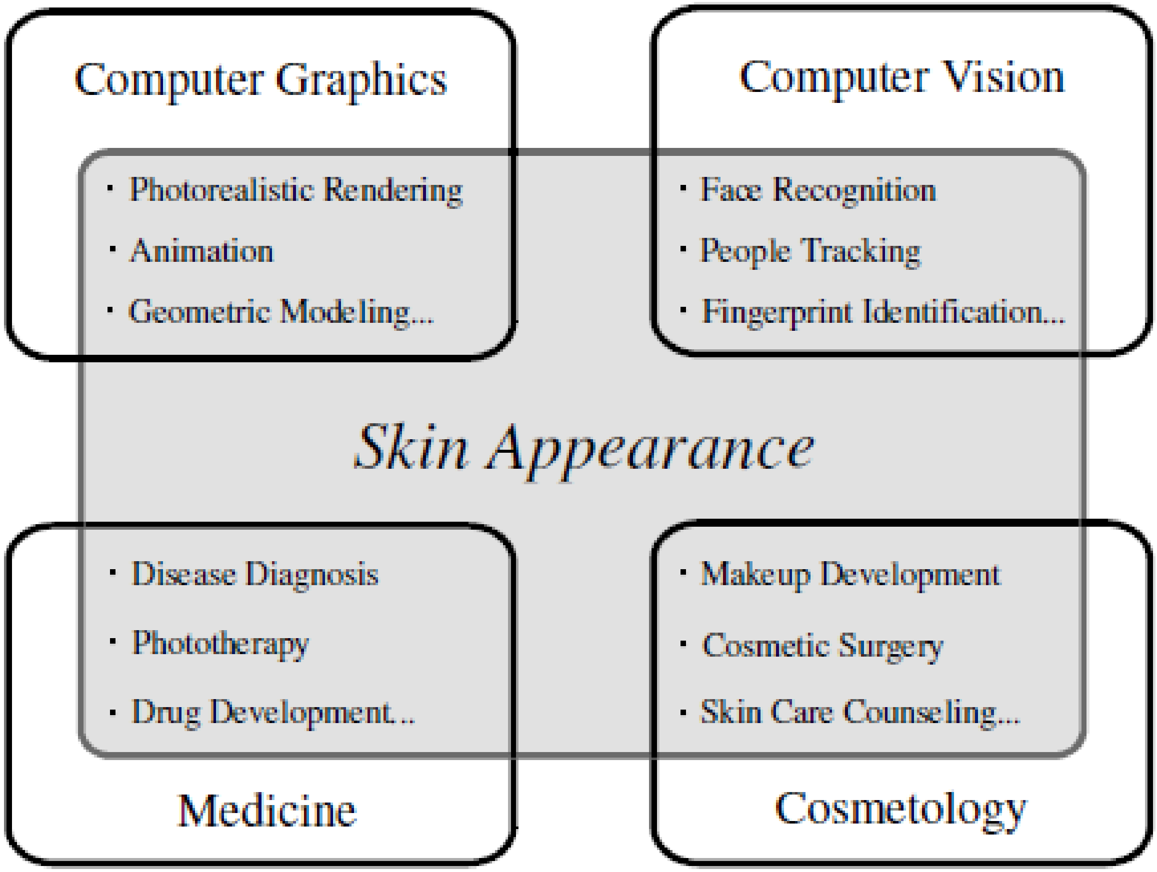

Takanori Iarashi, Ko Nisino, Shre K Nayar, The Appearance of Human Skin, Technical Report: CUCS-024-05, Columbia University, USA, 2005.

Human Skin Colour

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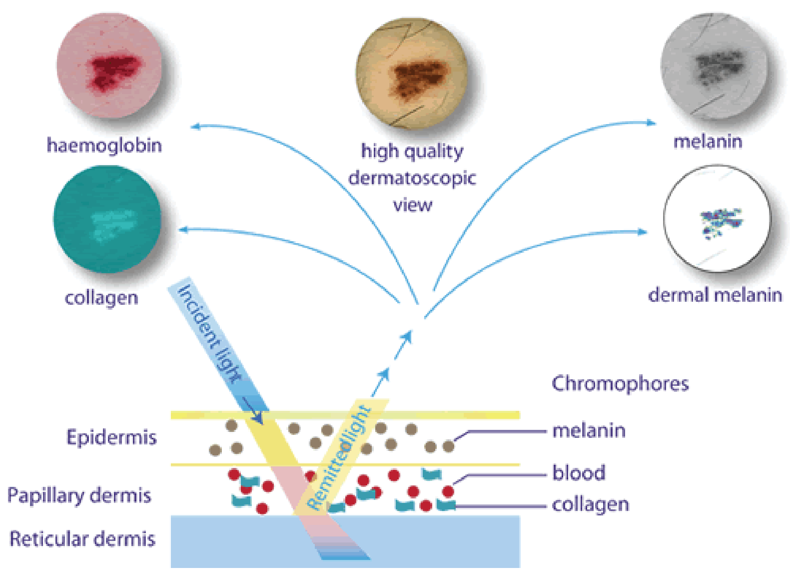
3D shape

Non-uniform colour distribution

Un-stable

Complicated structure



Human Skin Colour

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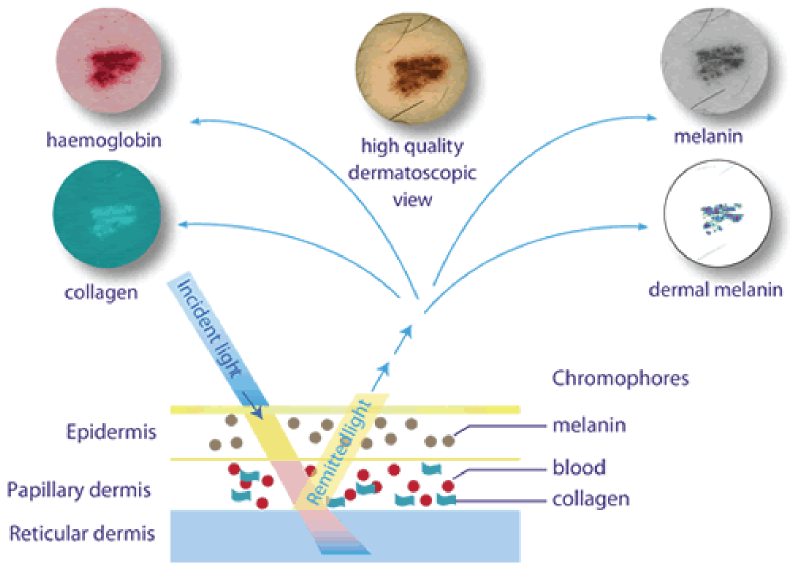
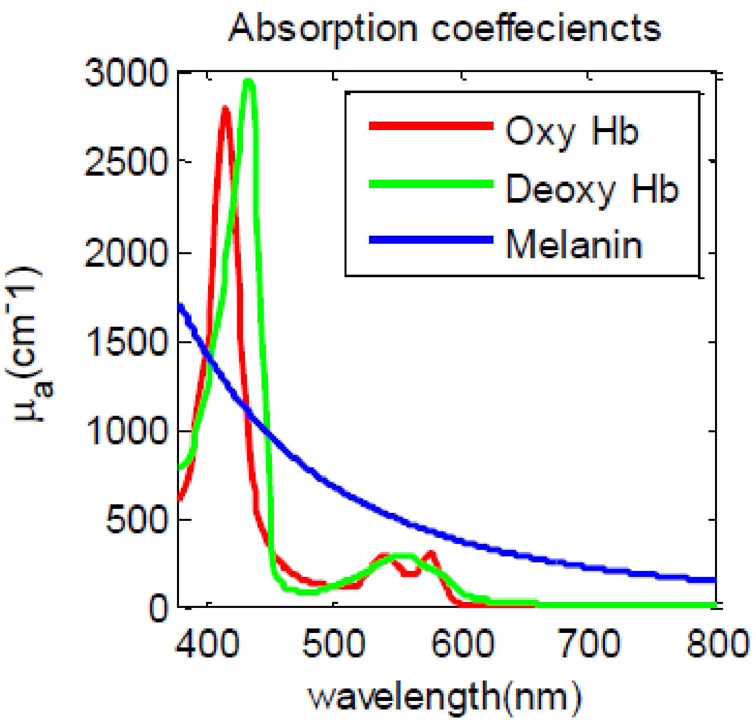
Skin colour is mainly determined by two chromophores:
melanin and haemoglobin
Melanin : in the basal layer of epidermis ->lightness/yellowness
Haemoglobin: contained in blood in dermis -> colour





Human skin colour

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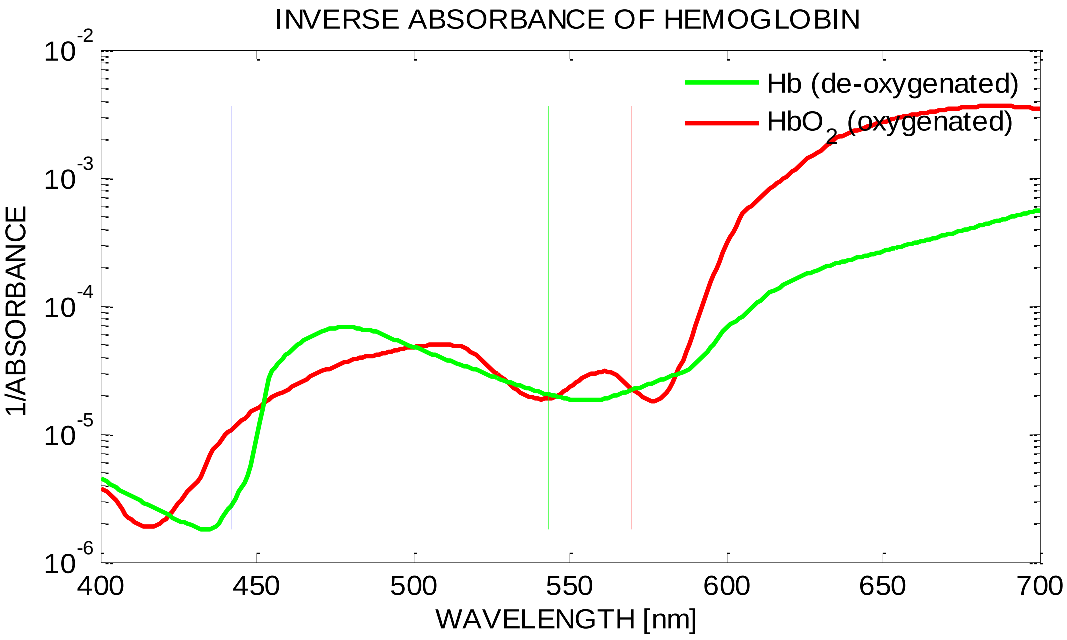

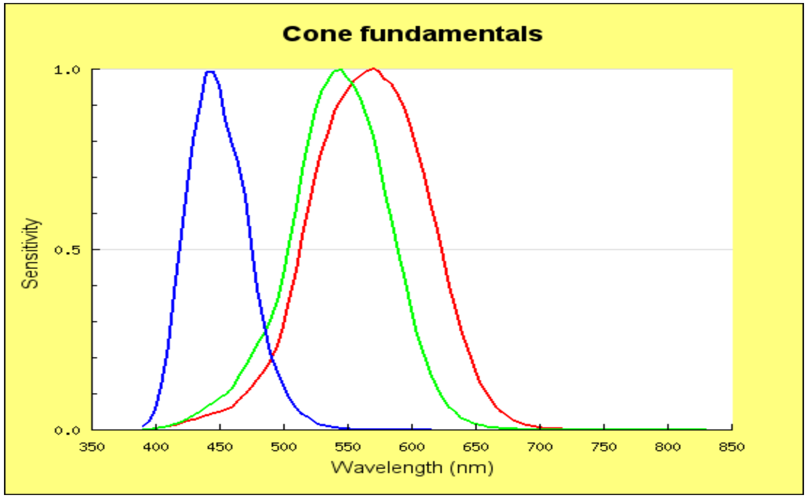

Why Spectral Reflectance?

- **Physical property**

  Independent of illumination

- **More informative**

  True colour simulation and reproduction

  Direct connects with skin chromophores

  - melanin, haemoglobin

Skin Colour Measurement

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Measurement Methods

- **Contact Methods**
  - **Spectrophotometer**

- **Non-contact Methods**
  - **Tele-spectroradiometer**
  - **Digital camera**
  - **Multi-spectral camera**

Why camera

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Spot Measurement

Imaging Measurement

Bare skin

Bare skin

CIE TC 1-92 : Skin Colour Database

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Year Established: 2013

Terms of Reference:

1. To investigate the uncertainty in skin color measurement and to recommend protocols for good measurement practice.

2. To tabulate skin color measurements that accord with these protocols covering different ethnicity, gender, age and body location.

Chair: K Xiao GB

Members: Paula Alessi US, Peter Bodrogi DE, Francisco Imai US, Peili Sun TW, Suchitra Sueeprasan TH, Wen Luo GB, Esther Perales ES, Changjun Li CN, Mengmeng Wang GB.

Skin colour measurement uncertainty

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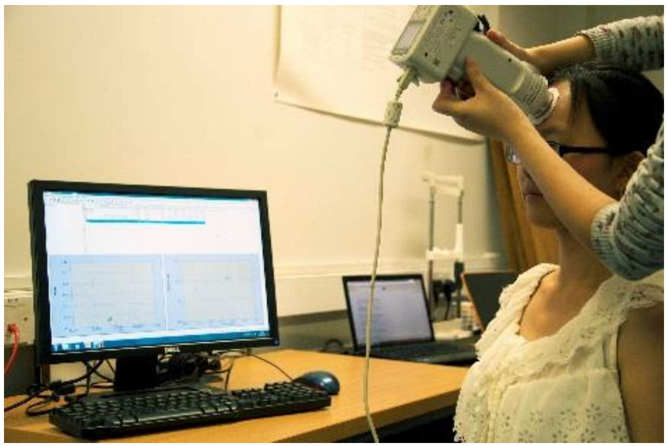
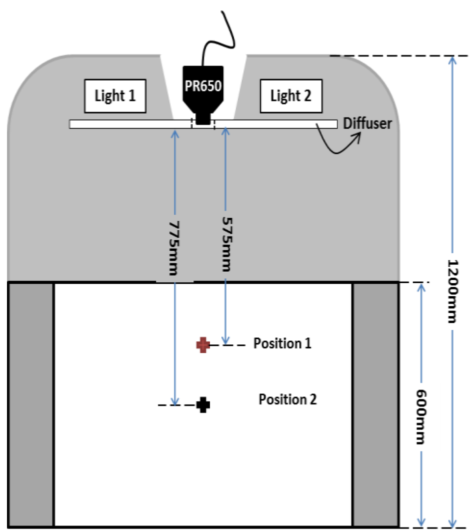
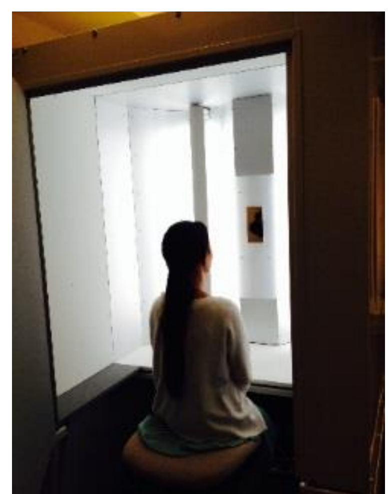


SPM

TSR





Measurement uncertainty (Repeatability)

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Mean MCDM (ΔE^*_{ab})		SPM						TSR	
		Repeatability		Pressure		Aperture size			
		CT (continuous)	CS (consecutive)	LP	HP	MA	SA	P1 (near)	P2 (far)
Human skin	Max.	0.87	1.82	1.56	1.82	0.94	1.82	0.97	1.19
	Min.	0.08	0.28	0.08	0.18	0.08	0.20	0.24	0.14
	Mean	0.37	0.63	0.34	0.40	0.35	0.39	0.51	0.53
PANTONE SkinTone™ Guide	Max.	0.15						0.10	
	Min.	0.02						0.08	
	Mean	0.07						0.09	

Mengmeng Wang, Kaida Xiao, Ronnier Luo, Michael Pointer, Vien Cheung, Sophie Wuerger, An investigation into the variability of skin colour measurements. Submitted to Color Research and Application

Measurement uncertainty (inter-instrument agreement)

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Instrument(s)	Cross-comparisons	Mean Colour Difference (ΔE*ab)
TSR	Position: P1 and P2	2.79
SPM	MA with different pressure: HP and LP	0.88
	SA with different pressure: HP and LP	1.82
	LP with different aperture size: MA and SA	2.48
	HP with different aperture size: MA and SA	3.04
TSR vs. SPM	TSR vs. SPM (SA / LP)	3.49
	TSR vs. SPM (MA / LP)	2.57
	TSR vs. SPM (SA / HP)	4.02
	TSR vs. SPM (MA / HP)	2.69
	TSR vs. SPM: PANTONE SkinTone™ Guide	0.88

Skin colour data collection

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- Nikon D7000 camera with DigiEye imaging system
- Tele-spectroradiometer: PhotoResearch SpectraScan PR650
- 3D camera: 3dMDTrio System
- Spectrophotometer: Konica Minolta CM-700d with CM-SA skin analysis software
- Verivide facial imaging lighting booth




Skin colour data collection

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	Year	Location	Ethnics Group	Method	Subjects	Body Location
1	2013	China	Chinese	SP	202	9
2	2013	UK	Caucasians	SP	187	9
3	2013	Iraq	Kurdish	SP	145	9
4	2014	Thailand	Thai	SP	426	6
5	2015	Pakistan	South Asian	SP	120	6
6	2013-2014	UK	Chinese, Caucasians, South Asians, African	SP, TSR, Camera	218	10
7	2014	China	Chinese, Caucasians, South Asians	SP, TSR	47	8

Skin Colour Appearance

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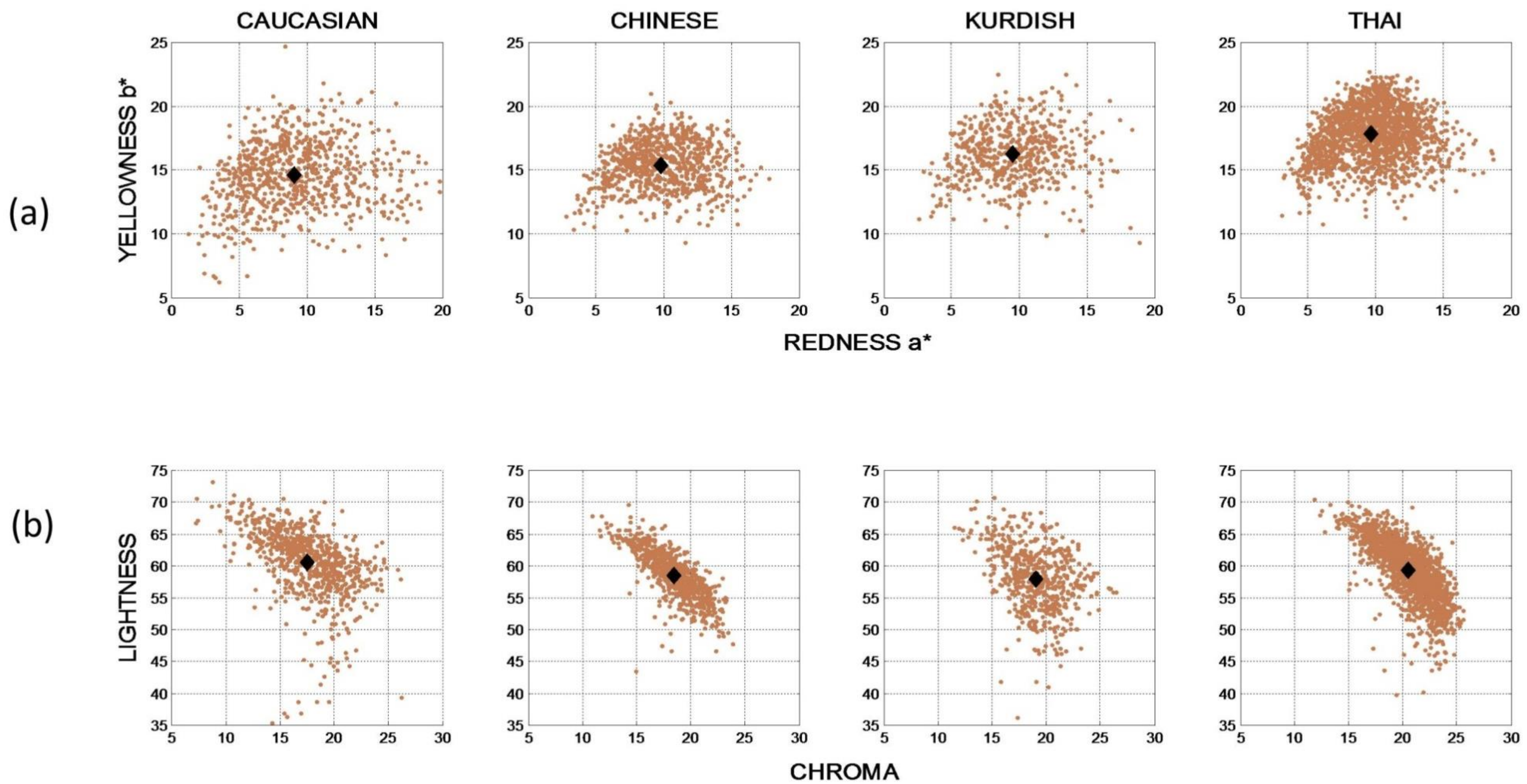

Large overlap in skin tones; smallest gamut in the chinese sample;

Kaida Xiao, Julian M Yates, Faraedon Zardawi, Suchitra Sueeprasan, Ningfang Liao, Lisey Gill, Changjun Li, Sophie Wuerger (2016) Characterising the variations in ethnic skin colours: a new calibrated data base for human skin. *Skin Research and Applications*

Skin colour gamut boundary

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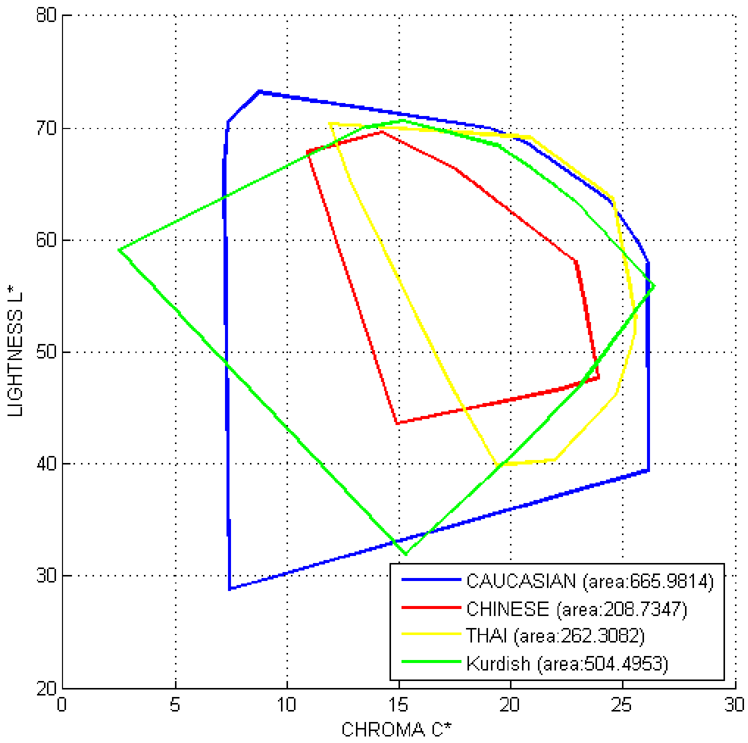

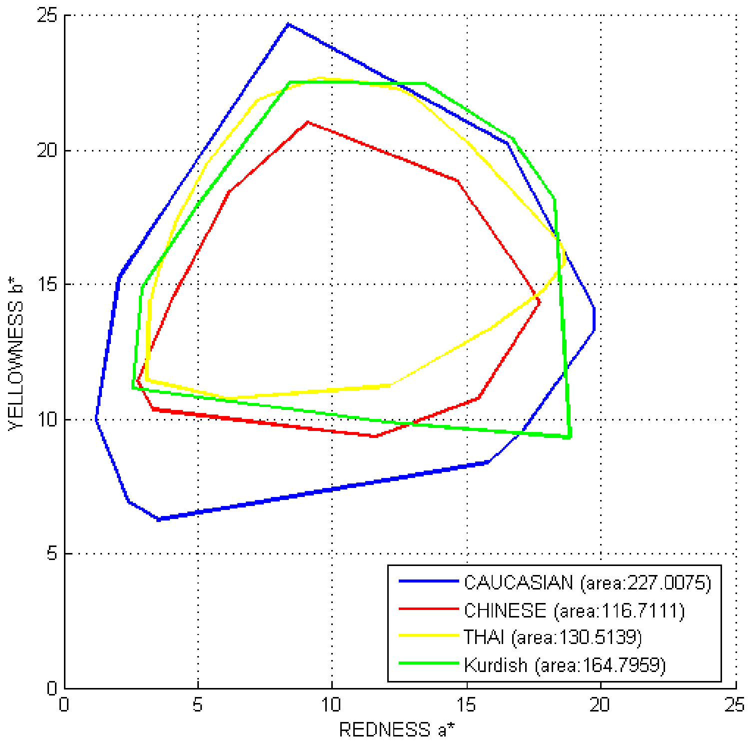

Skin Colour Cluster Analysis

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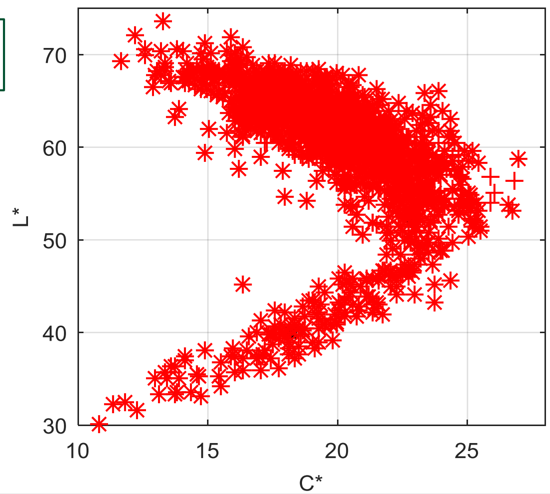
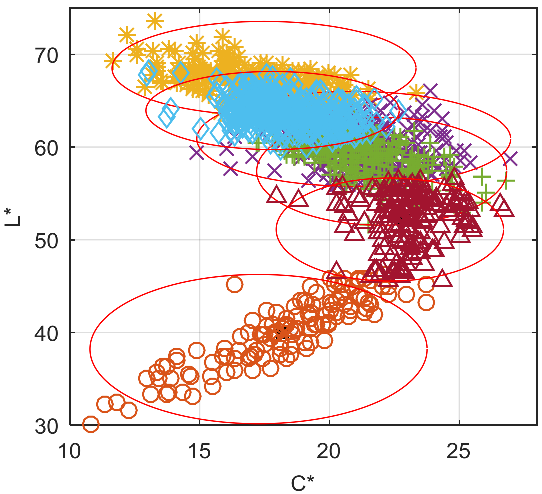
Viewing in L*-C* plane

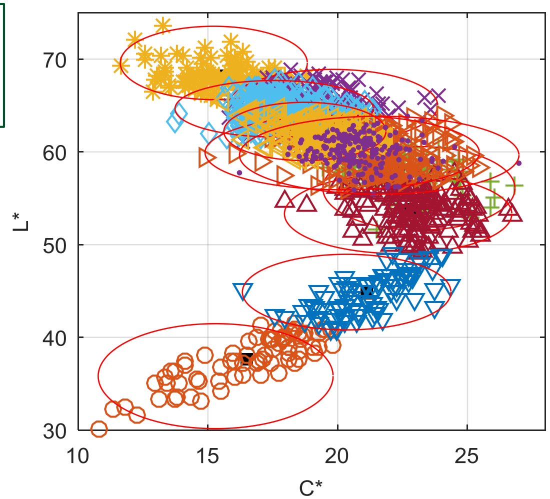
All data



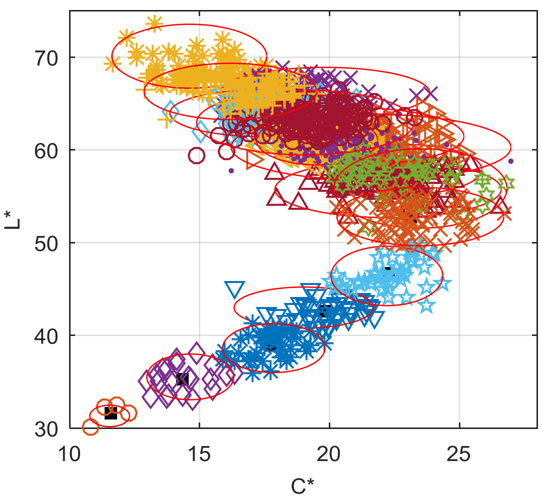
MCR 9%
6 clusters



MCR 5%
10 clusters



MCR 1%
17 clusters



Skin Spectra Analysis

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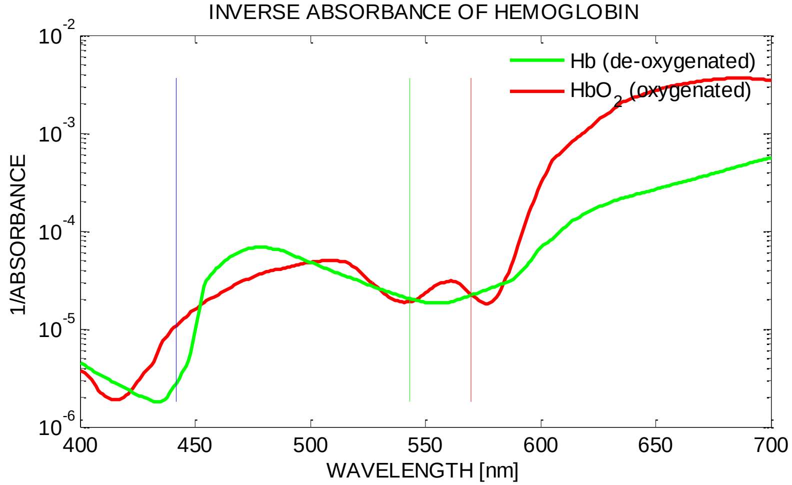
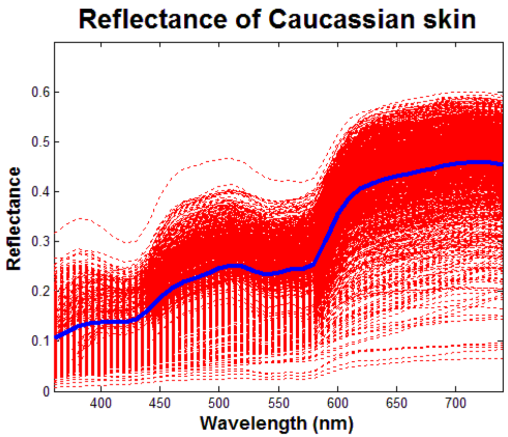
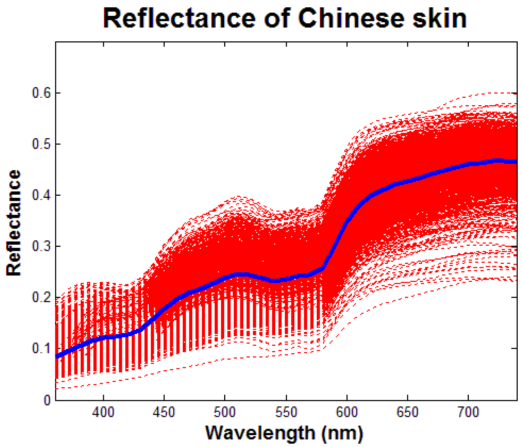
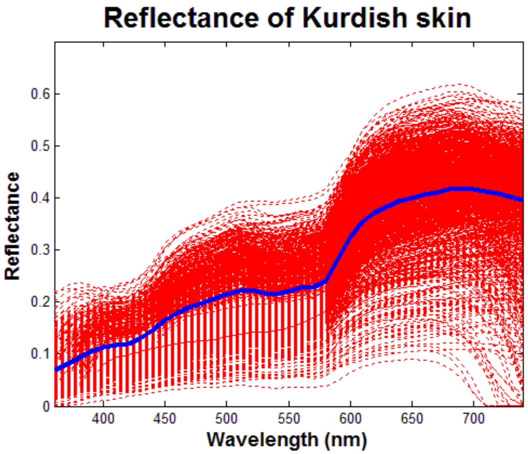


- Skin spectra follow the spectral shape of Hb
- Large variability in overall reflectance within each ethnic group
- Similar spectral shapes



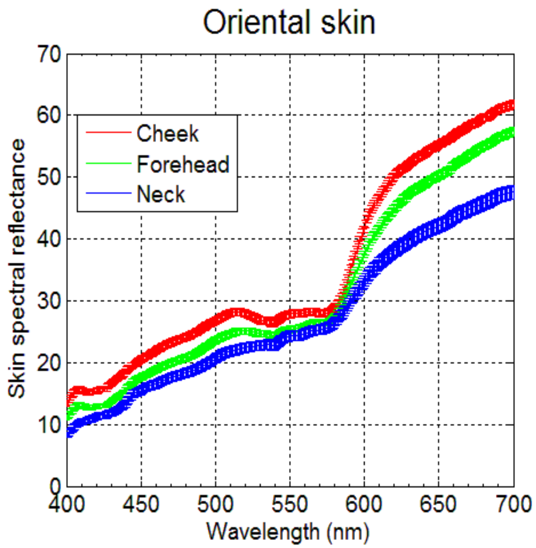


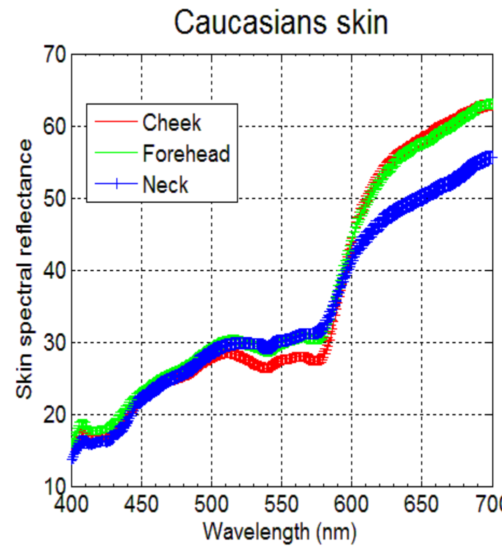


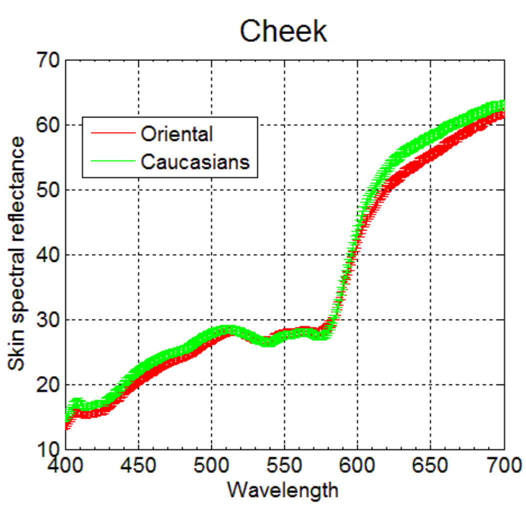
Kaida Xiao, Mngmeng Wang, Ronnier Luo, Changjun Li and Sophie Wuerger (2016), Characterisation of skin spectra in a Caucasian and Oriental sample, Proceeding of Electric Imaging 2016.

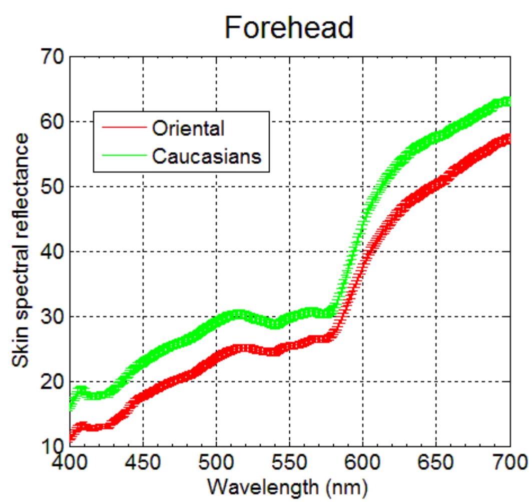
Skin Spectra Analysis

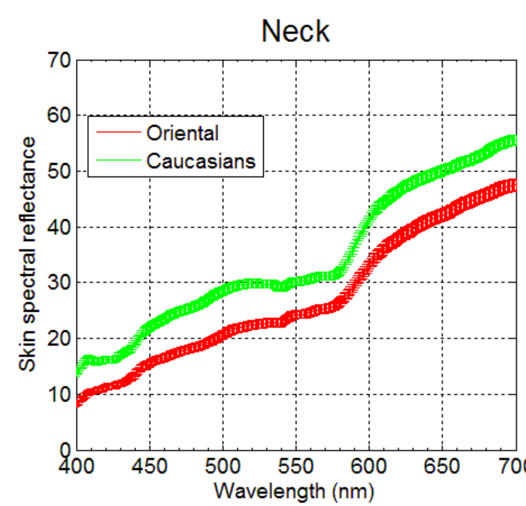
UNIVERSITY OF LEEDS





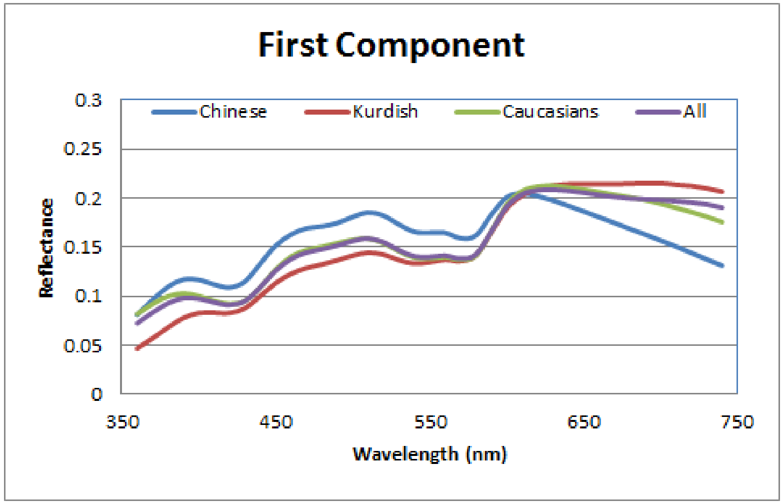


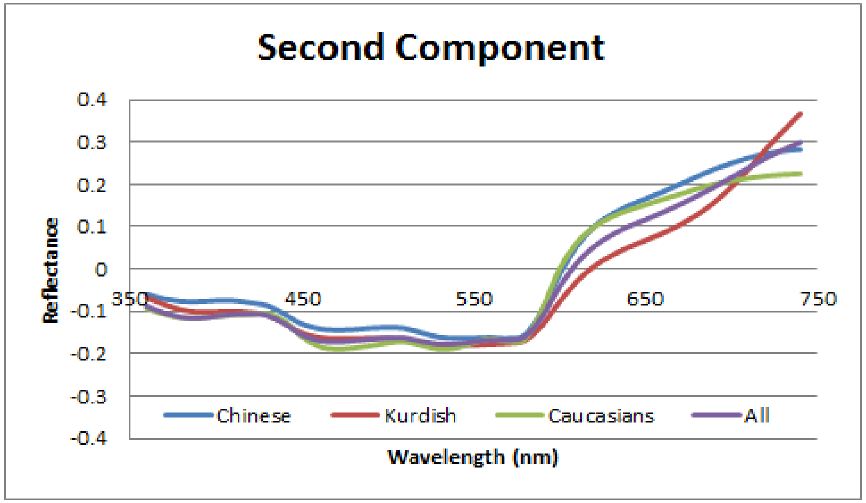


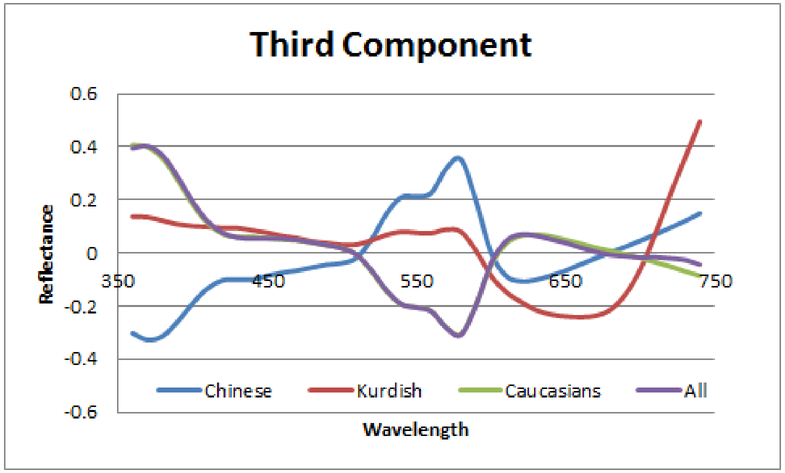


Skin Spectra Analysis

UNIVERSITY OF LEEDS







CCP (%)	First Component	Second Component	Third Component	Sum
Chinese	84.1	12.3	2.2	98.5
Kurdish	86.6	7.9	3.1	97.6
Caucasians	87.4	8.4	2.6	98.5
All	85.4	9.4	2.3	97.1

Kaida Xiao, Zhenghui Qin, Tushar Chauhan, Changjun Li and Sophie Wuerger (2014), Principal Component Analysis for Skin Reflectance Reconstruction, Proceeding 22nd Color and Imaging Conference.

Digital camera measurement

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Skin Image Acquisition

- Camera RGB
- Illumination and Camera setting

Spectral Measurement

- Measured using spectrophotometer or TSR
- Skin chart

Model to estimate skin spectra from camera RGB

- Spectral re-construction algorithm
- Skin spectral database

Skin spectra estimation

To estimate skin spectral reflectance from camera digital signals

Step 1: Camera profiling

- Camera colour characterisation (camera RGB to CIE XYZ)
- Camera spectral characterisation (Camera spectral sensitivity function estimation)

Step 2: Spectral reflectance re-construction

- CIE XYZ to spectral reflectance
- RGB to spectral reflectance with known camera spectral sensitivity

Skin image spectra estimation

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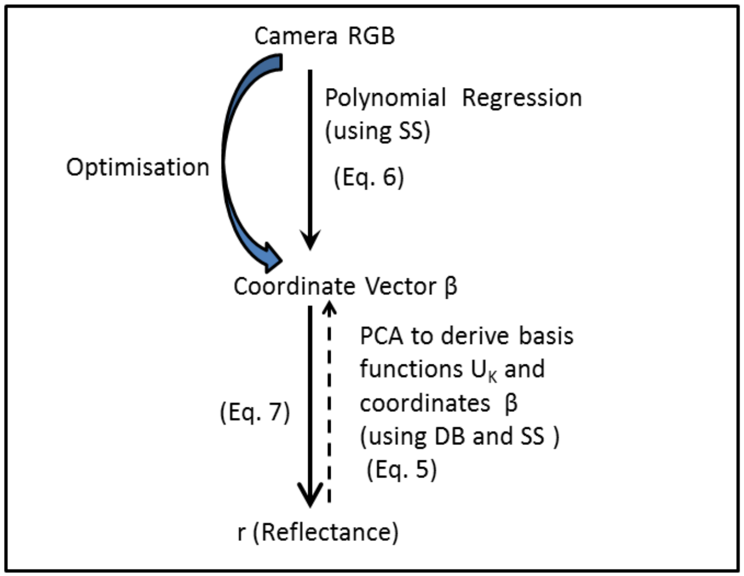

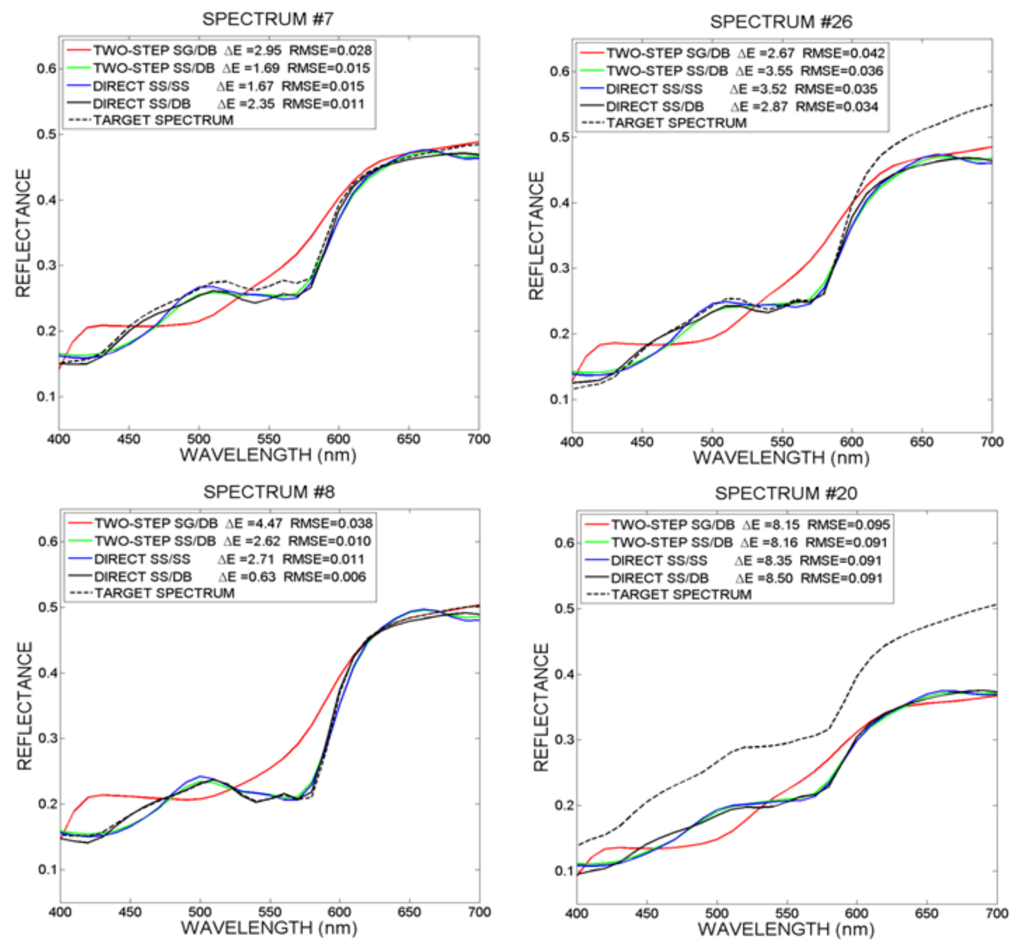

Kaida Xiao, Yuteng Zhu, Changjun Li, David Connah, Julian Yates and Sophie Wuerger (2016), Improved method for skin reflectance reconstruction from camera images, Optics Express, 24, 13, 14934-14950.

Skin colour discrimination

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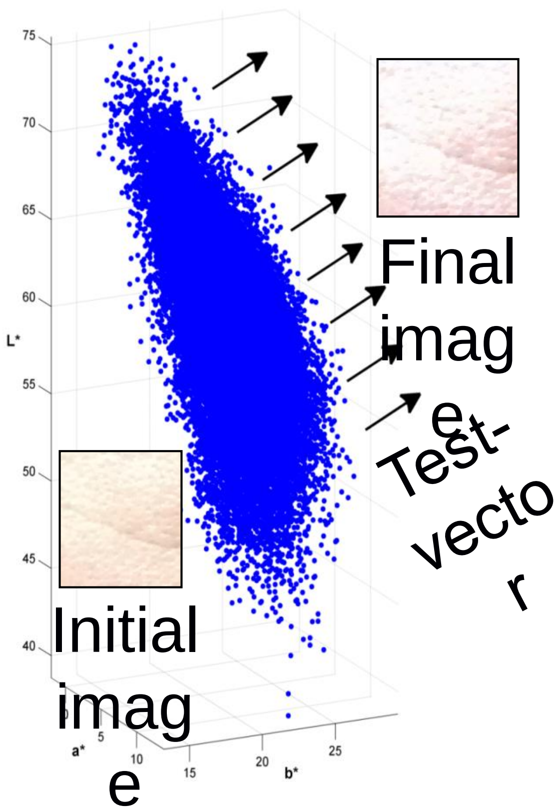
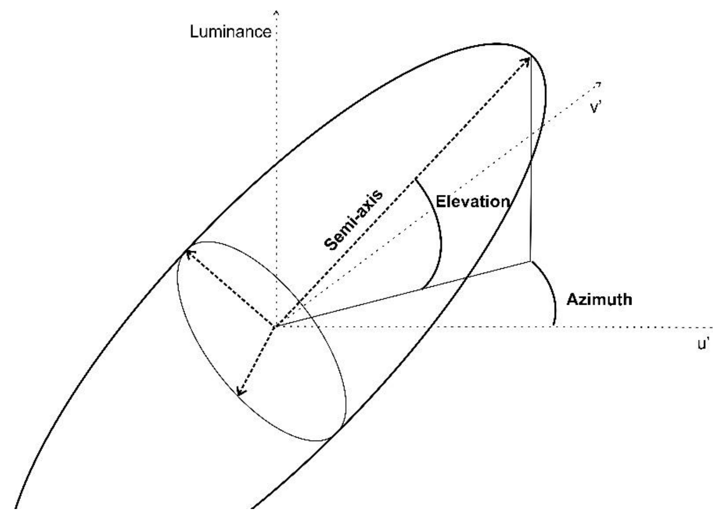
Test vectors: 14 directions in colour space: Luminance, u'v' plane

2 types of skin patches: caucasian, oriental

4-AFC procedure

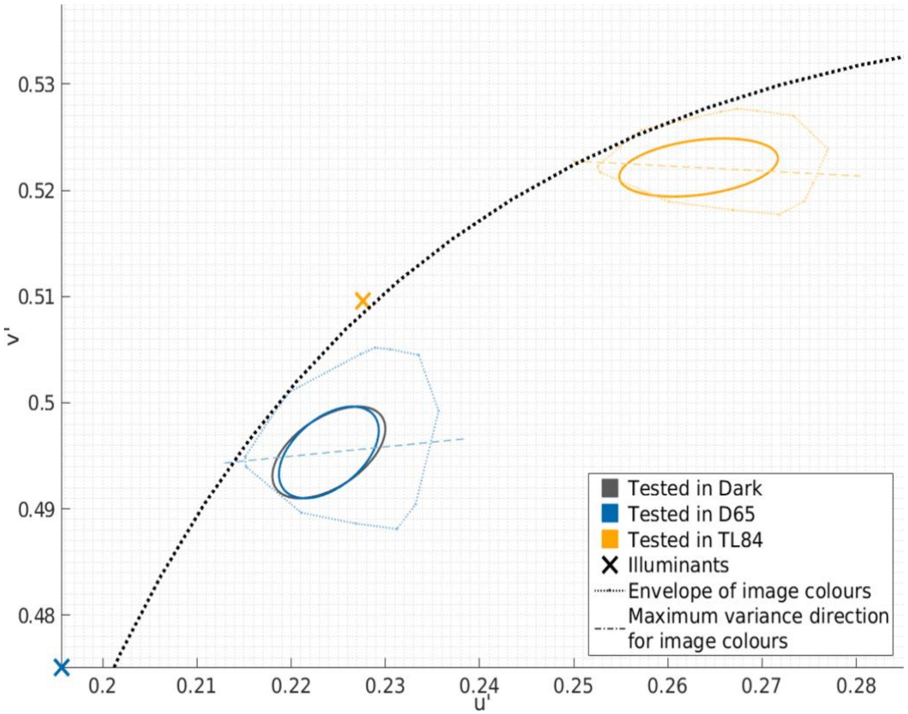




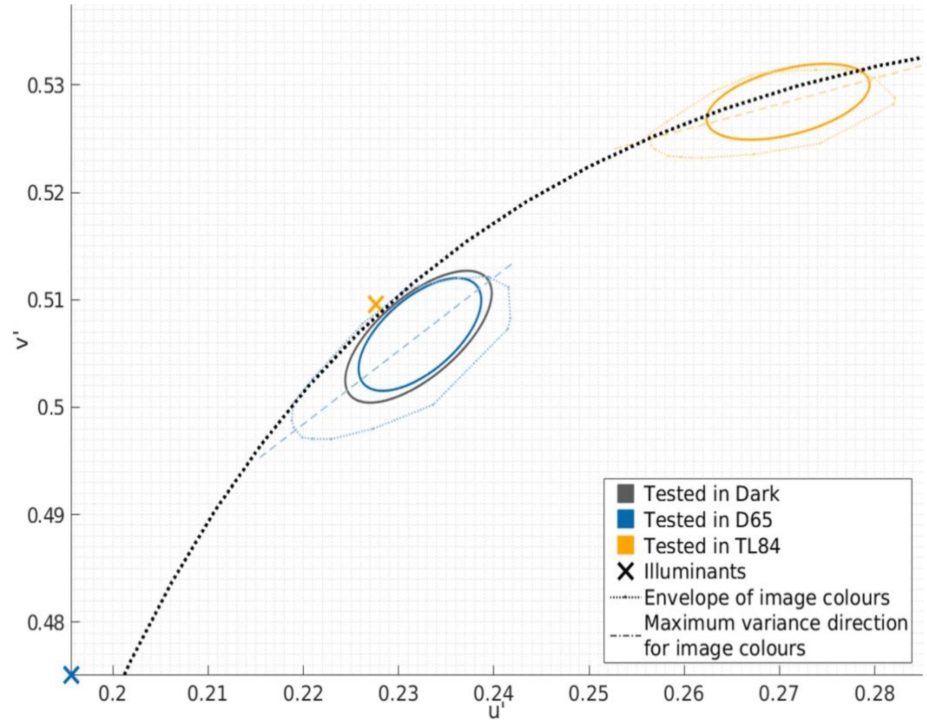
Volume of Ellipsoid, axes lengths, orientation

Skin colour discrimination

UNIVERSITY OF LEEDS



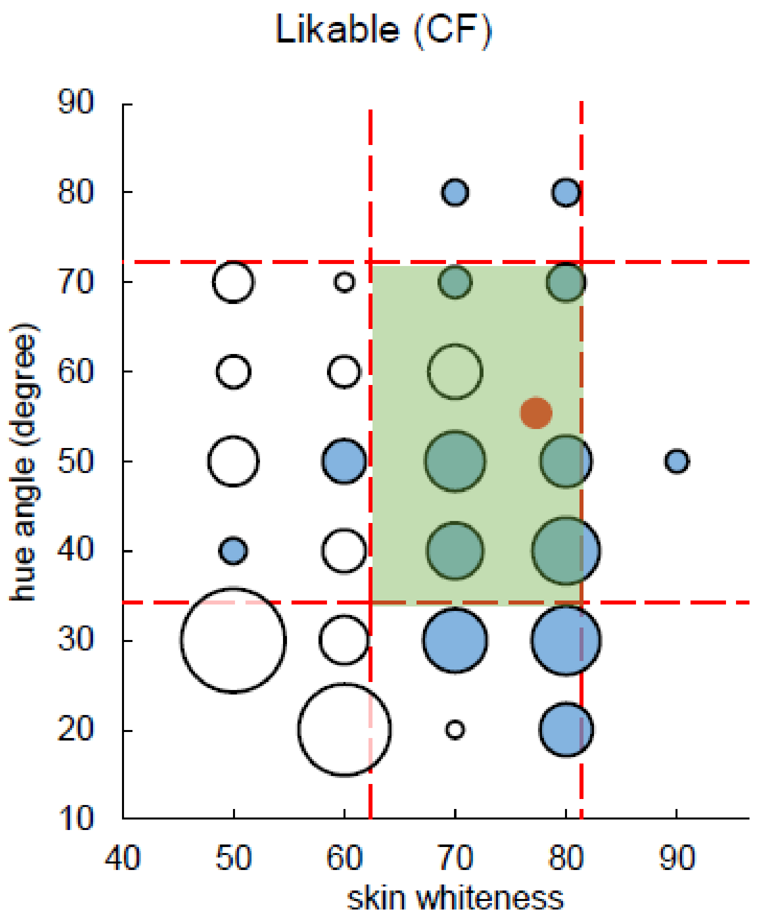
Mean projected ellipses for the Caucasians



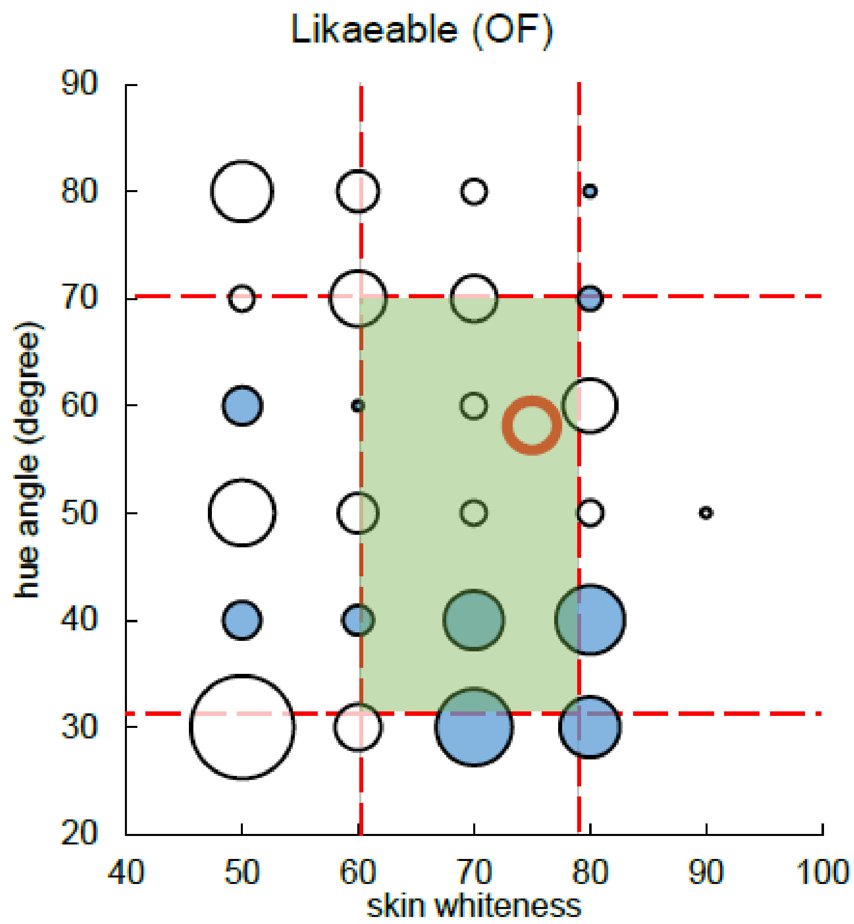
Mean projected ellipses for the Oriental

Tushar Chauhan, Kaida Xiao and Sophie Wuerger (2019), Chromatic and luminance sensitivity for skin and skinlike textures, Journal of Vision, 19 (1), 1-13.

Facial attactiveness



Caucasians face



Chinese face

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Thanks for your attention

k.xiao1@leeds.ac.uk

The display of medical images using CSDF colour calibration

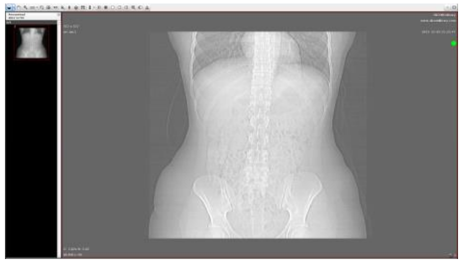
W Craig Revie

July 2015

Content incorporating feedback from the ICC MIWG

Medical images

Grayscale

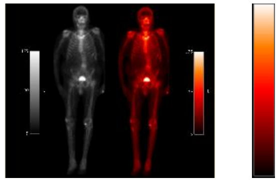


Xray

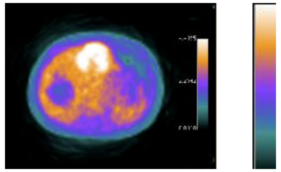
Computed Tomography

Magnetic Resonance

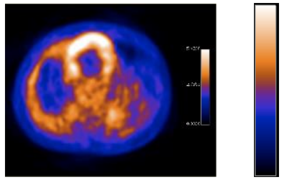
Pseudo-Color



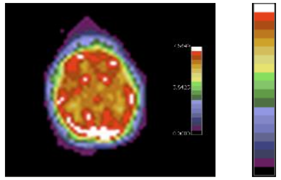
Hot Iron Color Palette



PET Color Palette



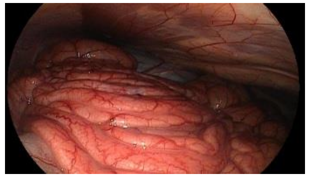
Hot Metal Blue Color Palette



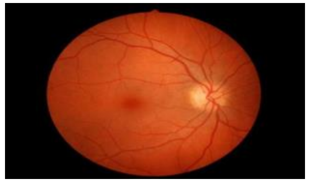
PET 20 Step Color Palette

Color

Digital Pathology Whole Slide Imaging



Endoscopy / Laparoscopy

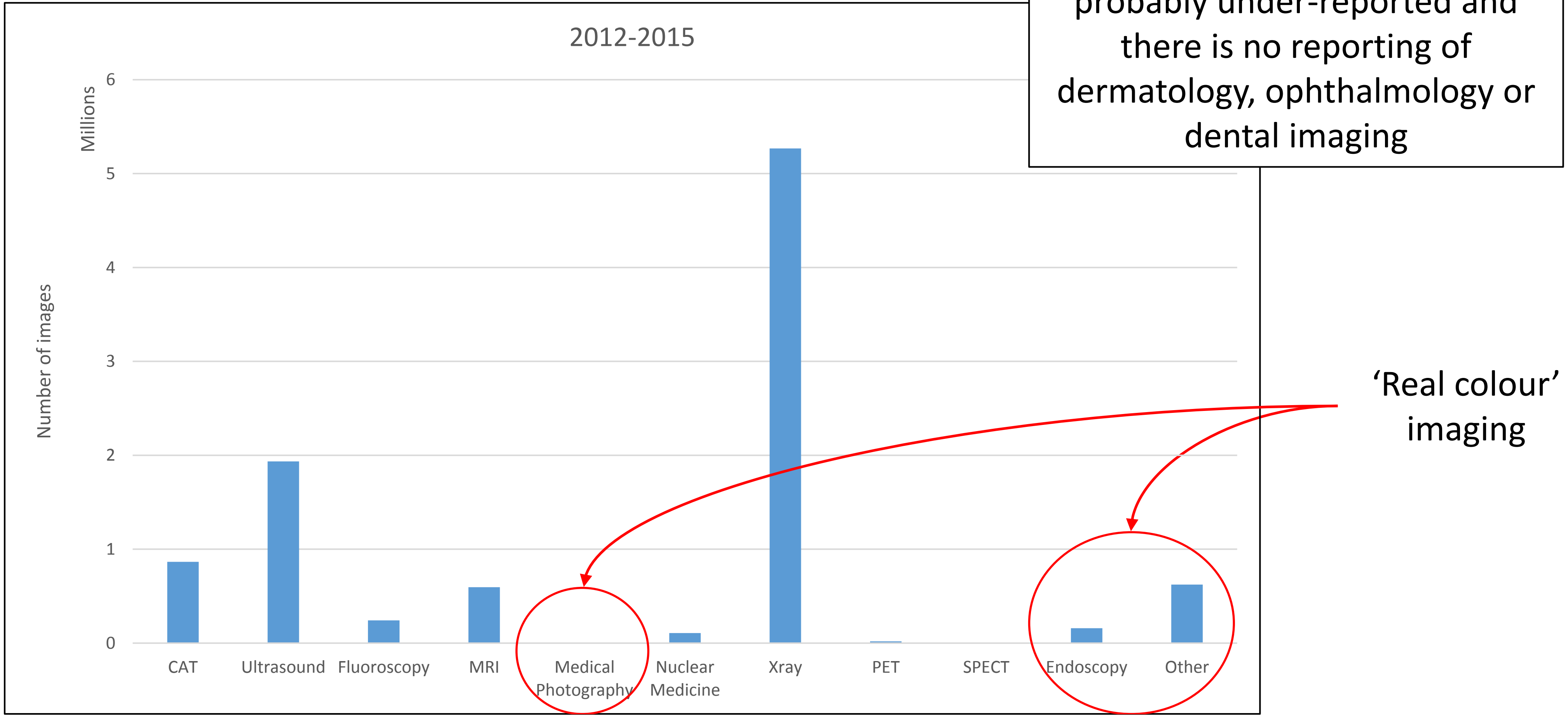


Ophthalmology

Medical Photography

Diagnostic imaging (England)

Note: medical photography is probably under-reported and there is no reporting of dermatology, ophthalmology or dental imaging



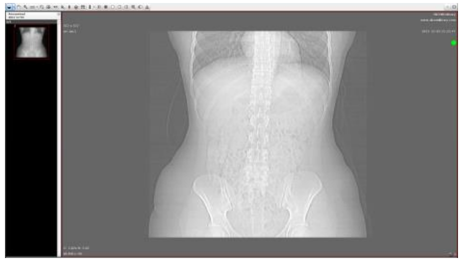
Source: http://www.england.nhs.uk/statistics/statistical-work-areas/diagnostic-imaging-dataset

Current status

- The majority of medical images have no inherent colour but are often displayed using pseudo colour to aid diagnosis
- Standards for medical displays currently only define grey calibration requirements
  - DICOM PS3.14 2015c - Grayscale Standard Display Function
  - IEC 62563-1:2009 Medical electrical equipment - Medical image display systems - Part 1: Evaluation methods
  - Gray Tracking in Medical Color Displays - A report of the AAPM Task Group 196
- Key organisations
  - American Association of Physicists in Medicine (AAPM)
  - IEC TC 62/SC 62B Diagnostic imaging equipment
  - ICC Medical Imaging Working Group
- Increasingly colour provides important diagnostic information
  - Colour standardisation work has been started under the names dRGB, mRGB, CSDF

Medical images

Grayscale



Xray

Computed Tomography

Magnetic Resonance

Display calibration: Grayscale Standard Display Function (GSDF)

DICOM PS3.14 2015b - Grayscale Standard Display Function

7.1 GENERAL FORMULAS

The Grayscale Standard Display Function is defined by a mathematical interpolation of the 1023 Luminance levels derived from Barten's model. The Grayscale Standard Display Function allows us to calculate luminance, L, in candelas per square meter, as a function of the Just-Noticeable Difference (JND) Index, j:

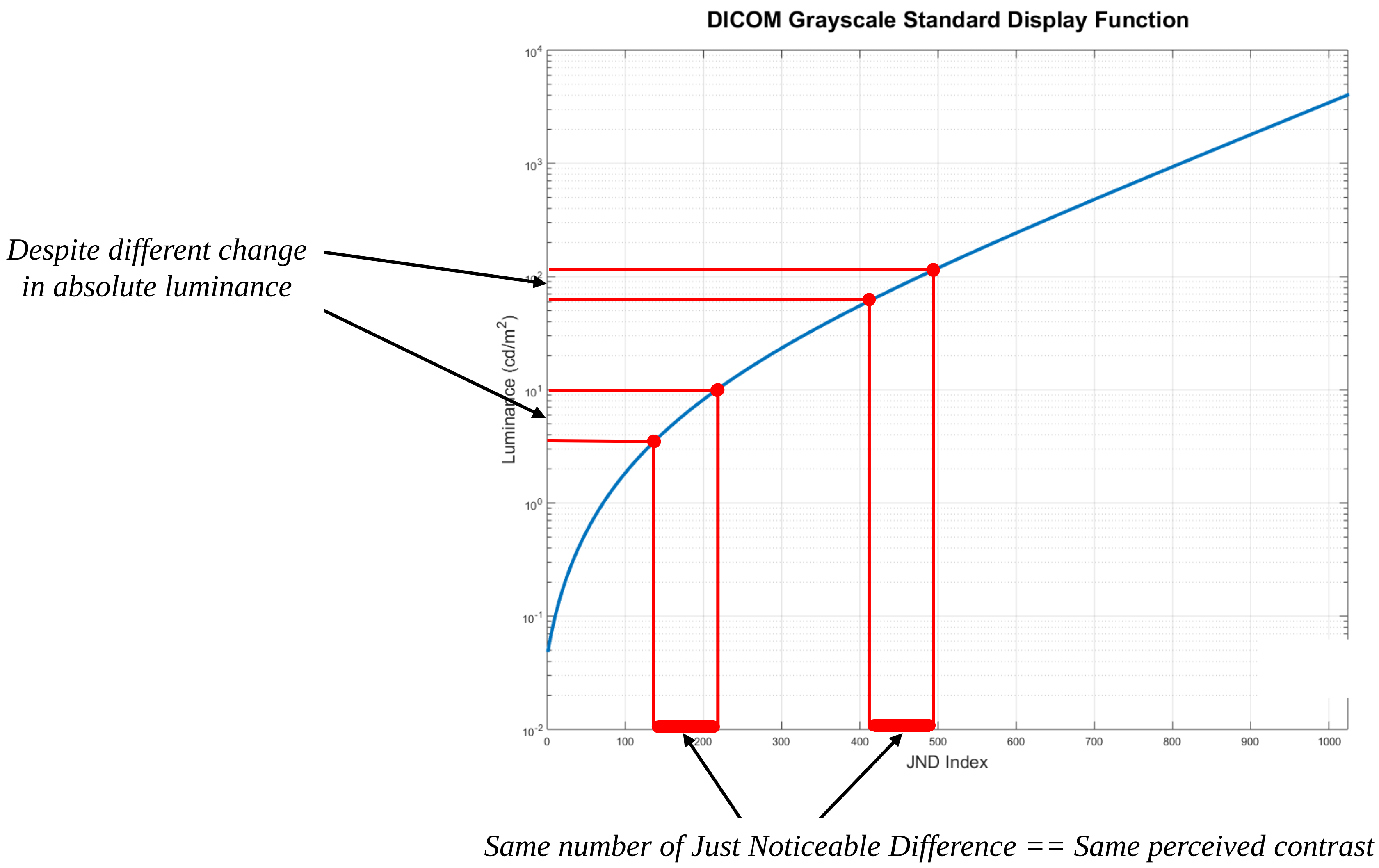
$$\log_{10} L(j) = \frac{a + c \cdot Ln(j) + e \cdot (Ln(j))^2 + g \cdot (Ln(j))^3 + m \cdot (Ln(j))^4}{1 + b \cdot Ln(j) + d \cdot (Ln(j))^2 + f \cdot (Ln(j))^3 + h \cdot (Ln(j))^4 + k \cdot (Ln(j))^5}$$

with Ln referring to the natural logarithm, j the index (1 to 1023) of the Luminance levels L_j of the JNDs, and a = -1.3011877, b = -2.5840191E-2, c = 8.0242636E-2, d = -1.0320229E-1, e = 1.3646699E-1, f = 2.8745620E-2, g = -2.5468404E-2, h = -3.1978977E-3, k = 1.2992634E-4, m = 1.3635334E-3.

The logarithms to the base 10 of the Luminance L_j are very well interpolated by this function over the entire Luminance Range. The relative deviation of any log(Luminance)-value from the function is at most 0.3%, and the root-mean-square-error is 0.0003. The continuous representation of the Grayscale Standard Display Function permits a user to compute discrete JNDs for arbitrary start levels and over any desired Luminance Range.

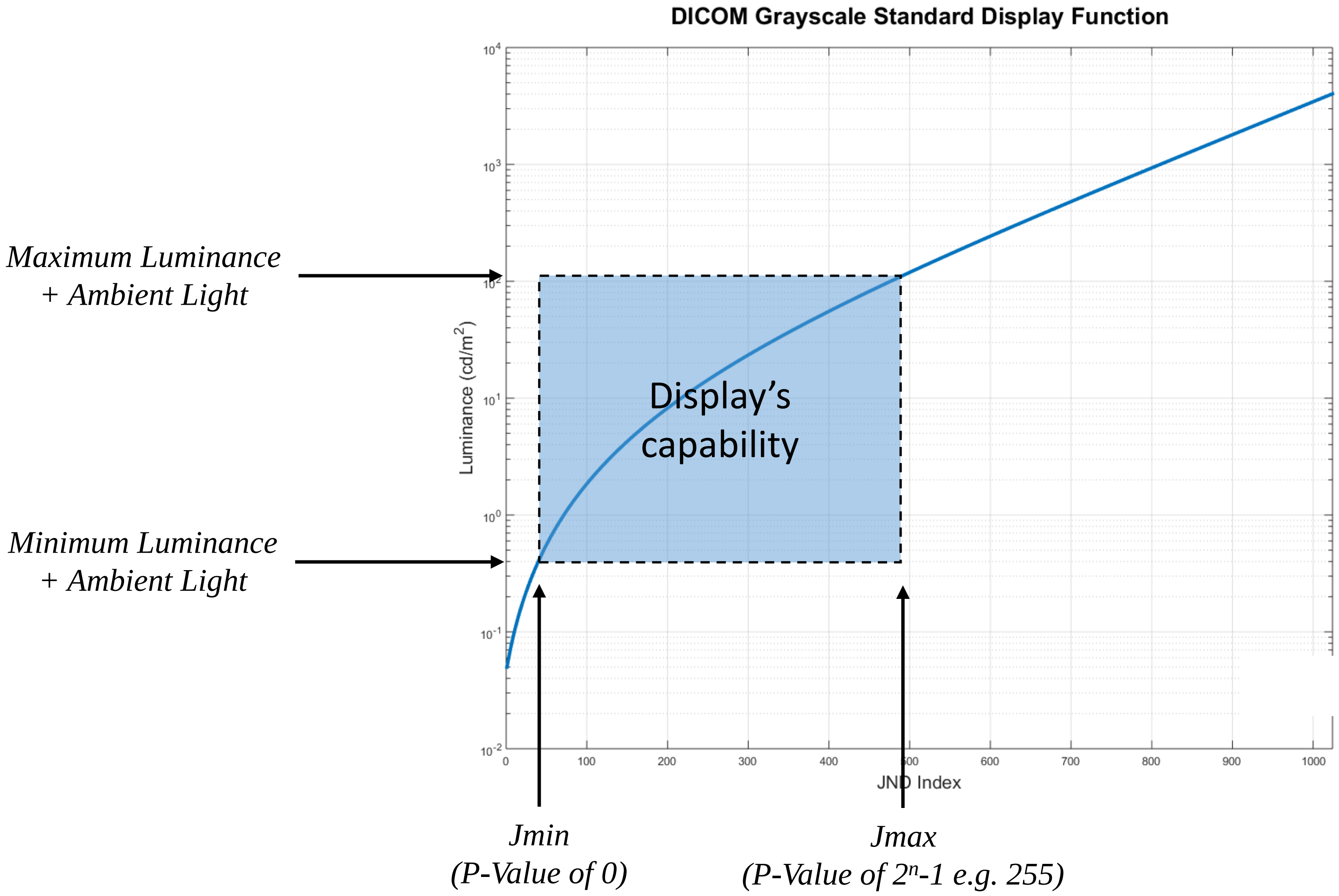
P.G.J. Barten: Physical model for the Contrast Sensitivity of the human eye. Proc. SPIE **1666**, 57-72 (1992)

Display calibration: Grayscale Standard Display Function (GSDF)



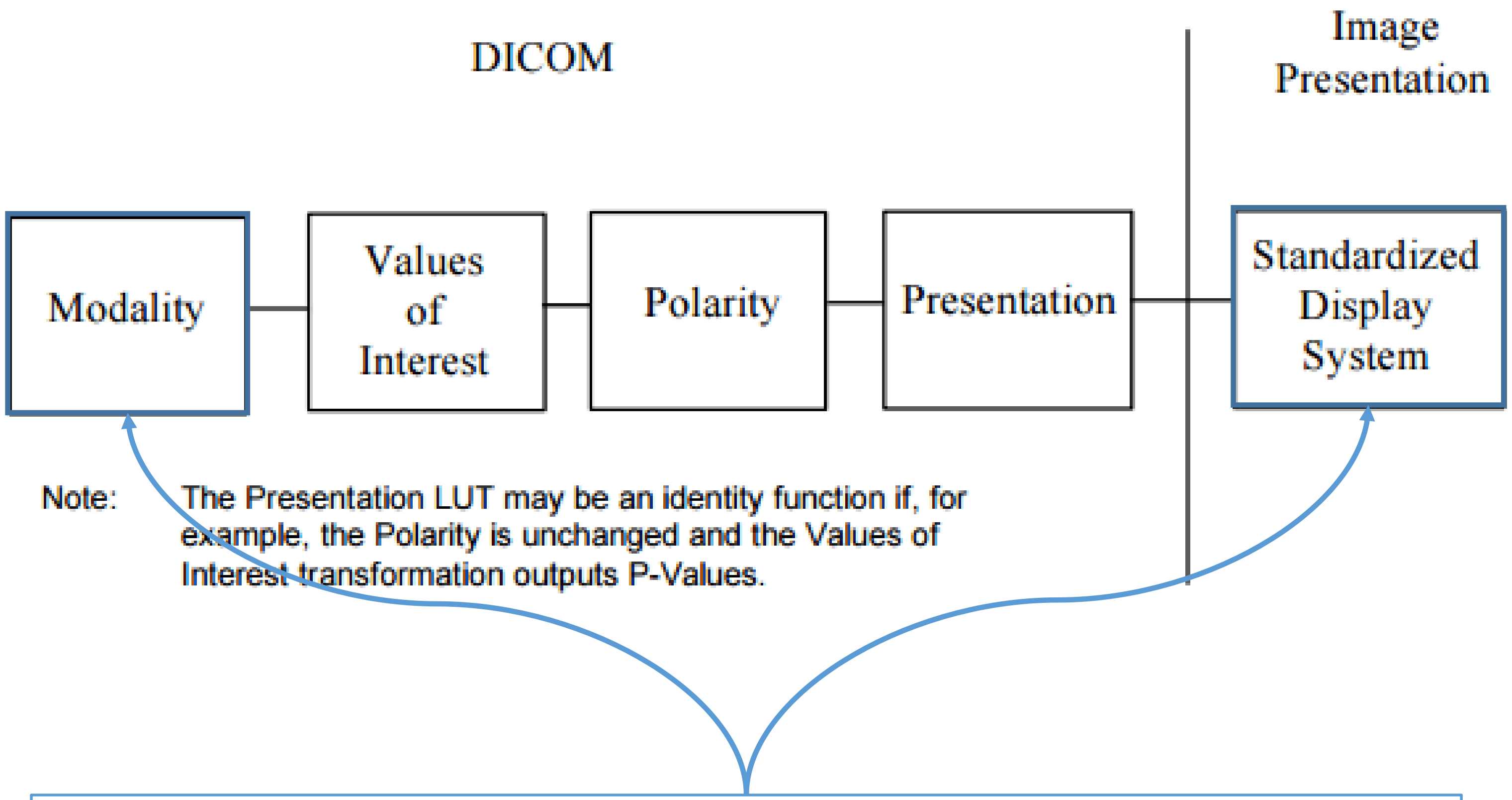
$$\log_{10} L(j) = \frac{a + c \cdot Ln(j) + e \cdot (Ln(j))^2 + g \cdot (Ln(j))^3 + m \cdot (Ln(j))^4}{1 + b \cdot Ln(j) + d \cdot (Ln(j))^2 + f \cdot (Ln(j))^3 + h \cdot (Ln(j))^4 + k \cdot (Ln(j))^5}$$

Display calibration: Grayscale Standard Display Function (GSDF)



$$\log_{10} L(j) = \frac{a + c \cdot Ln(j) + e \cdot (Ln(j))^2 + g \cdot (Ln(j))^3 + m \cdot (Ln(j))^4}{1 + b \cdot Ln(j) + d \cdot (Ln(j))^2 + f \cdot (Ln(j))^3 + h \cdot (Ln(j))^4 + k \cdot (Ln(j))^5}$$

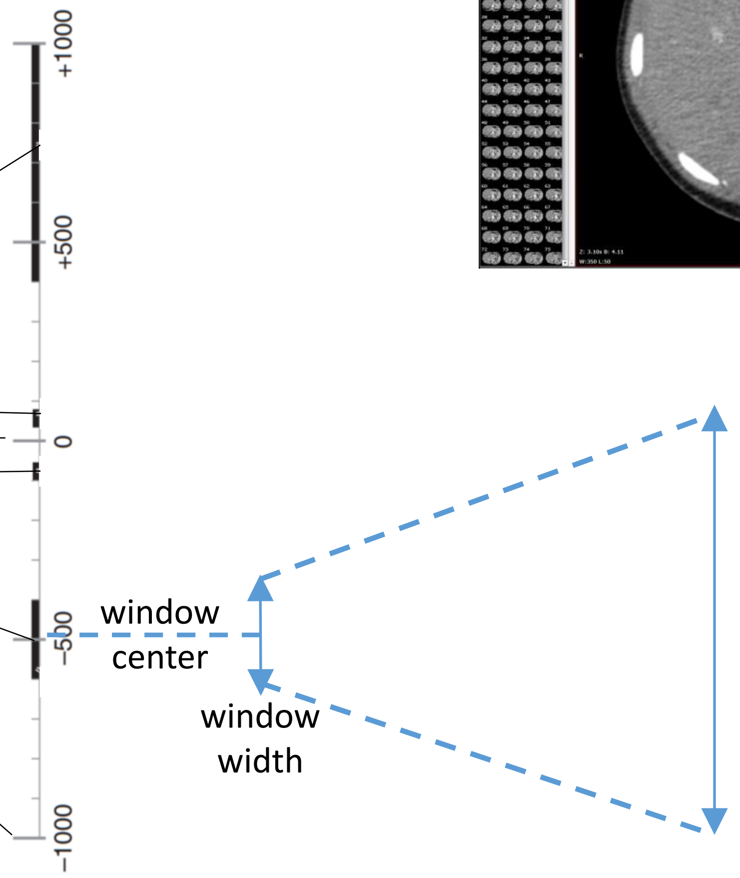
DICOM image presentation



In many cases the range of values captured by the imaging modality is substantially greater than the range of values that can be displayed

Example CT scan

+400 -> +1000	Bone
+40 -> +80	Soft tissue
0	Water
-100 -> -60	Fat
-600 -> -400	Lung
-1000	Air



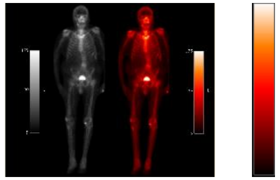
Hounsfield Unit (HU) scale of CT numbers

Standards for display of ‘greyscale’ images

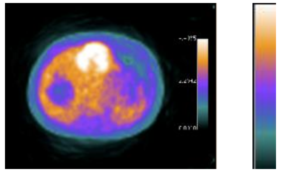
- Digital Imaging and Communications in Medicine (DICOM)
  - De-facto industry standard administered by NEMA/MITA
  - Specification is available from http://dicom.nema.org/
- IEC 62563-1:2009 Medical electrical equipment - Medical image display systems – Part 1: Evaluation methods
- Gray Tracking in Medical Color Displays - A report of the AAPM Task Group 196
  - Method for characterizing the grayscale tracking performance of colour displays
  - Findings suggest the capabilities and limitations of various colour measurement instruments
  - Proposes methods for characterizing the grayscale degradation regarding the chromaticity of colour monitors
  - Can be used to further the establish standards and procedures that aid in the quality testing of colour displays and colour measurement instrumentation

Medical images

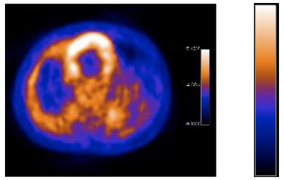
Pseudo-Color



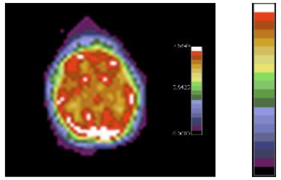
Hot Iron Color Palette



PET Color Palette

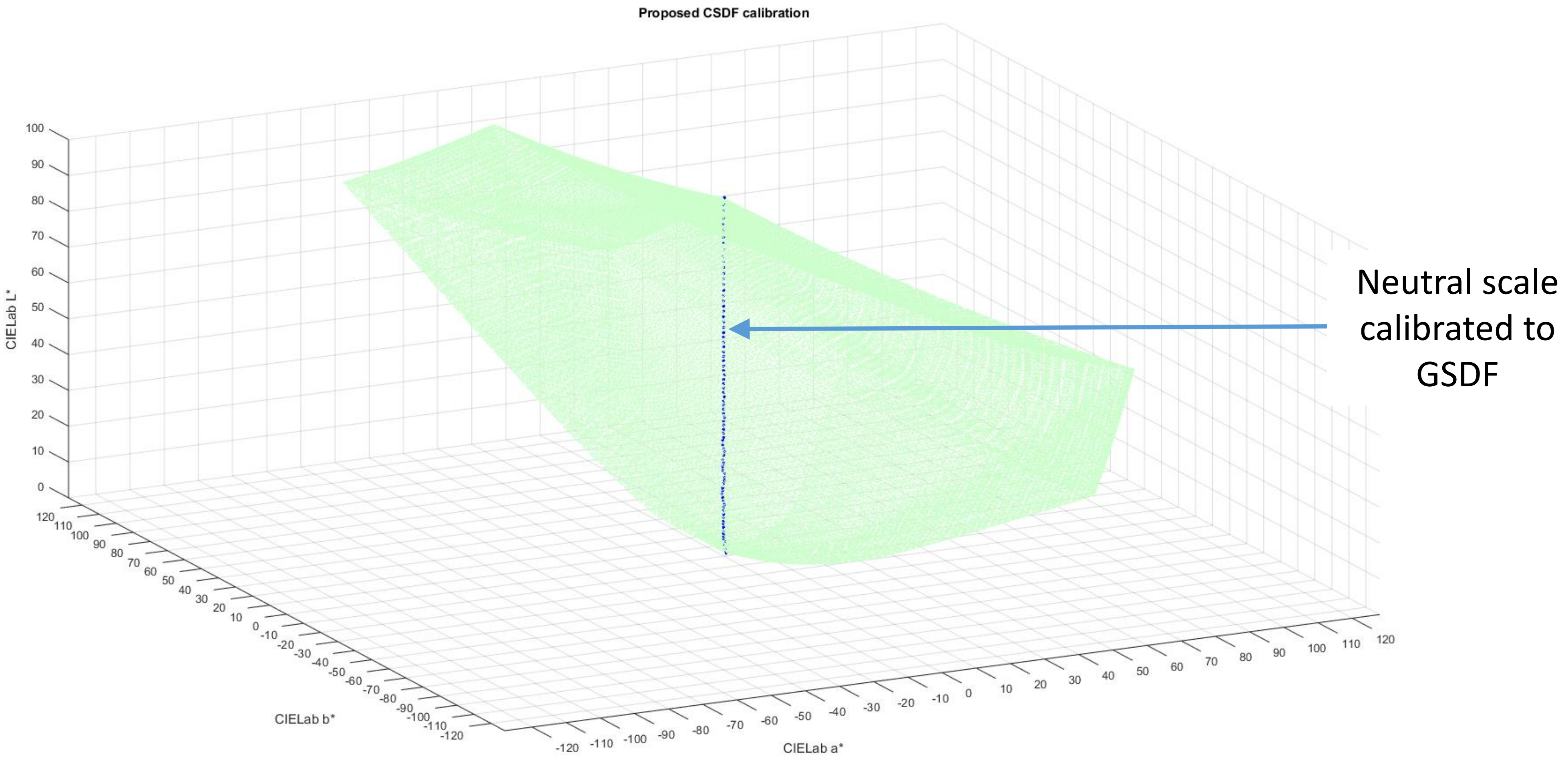


Hot Metal Blue Color Palette



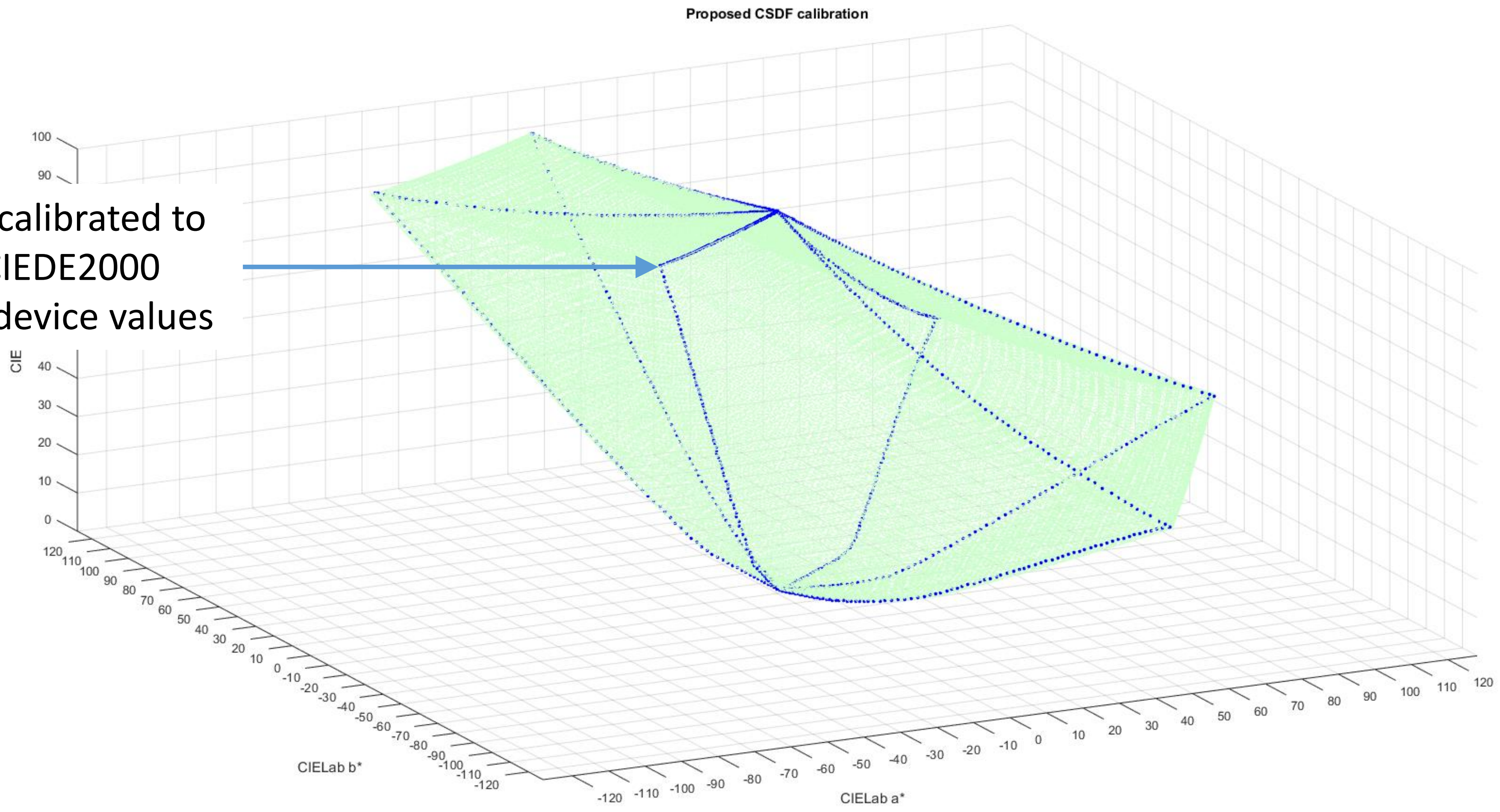
PET 20 Step Color Palette

CSDF proposal extends GSDF for pseudo-colour



CSDF proposal extends GSDF for pseudo-colour

Chromatic scales calibrated to ensure equal CIEDE2000 spacing between device values

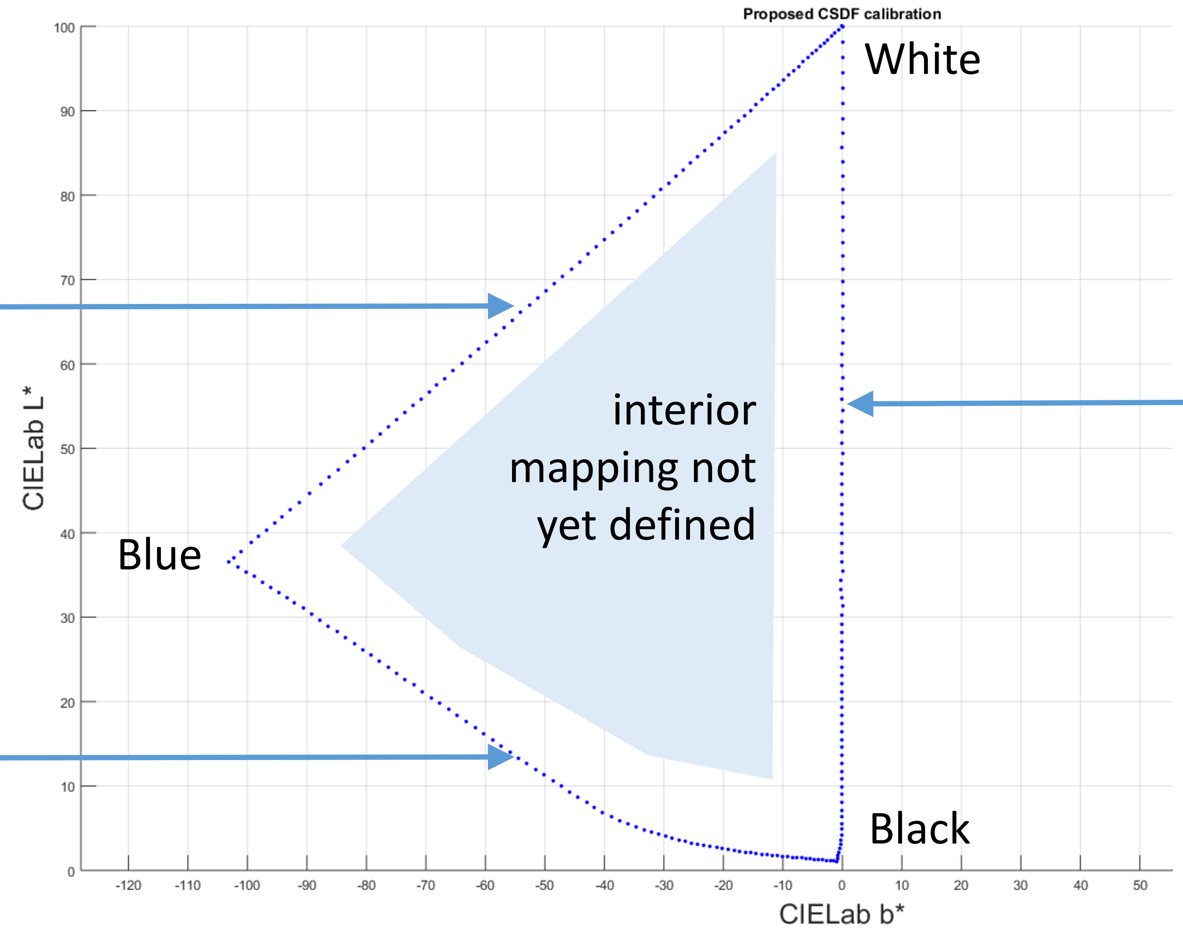


CSDF proposal extends GSDF for pseudo-colour

Similar calibration adjustment performed on other primary and secondary scales

Blue-White scale calibrated to ensure equal CIEDE2000 spacing between device values

Blue-Black scale calibrated to ensure equal CIEDE2000 spacing between device values

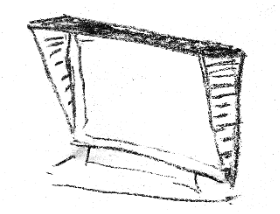


Neutral scale calibrated to GSDF

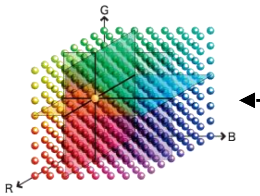
Note that spacing of values on Blue-White and Blue-Black scales will usually be different

Example: same display calibrated to CSDF and sRGB

Does calibration to CSDF improve the display of pseudo colour images?
CSDF calibration should result in better perceptual spacing of primaries and secondaries.



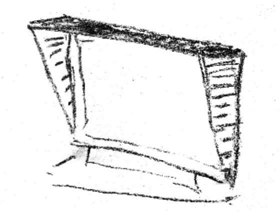
- Neutral scale = GSDF
- *Pairs of neighbouring primary or secondary colours have the same CIEDE2000 colour difference*



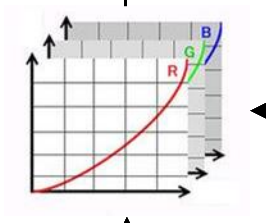
CSDF
cLUT

RGB

CSDF calibrated display



- sRGB primaries



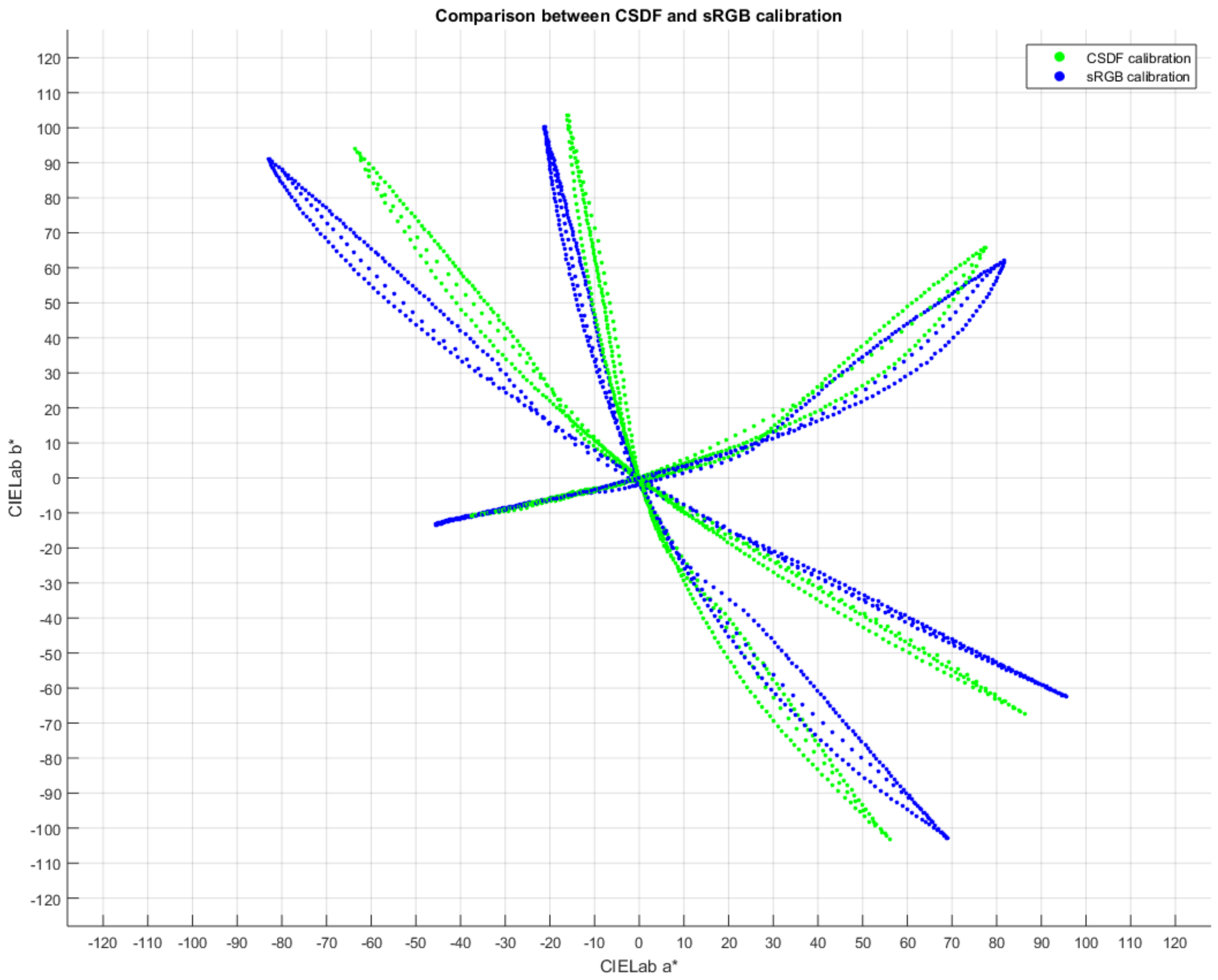
sRGB
1-D LUTs

RGB

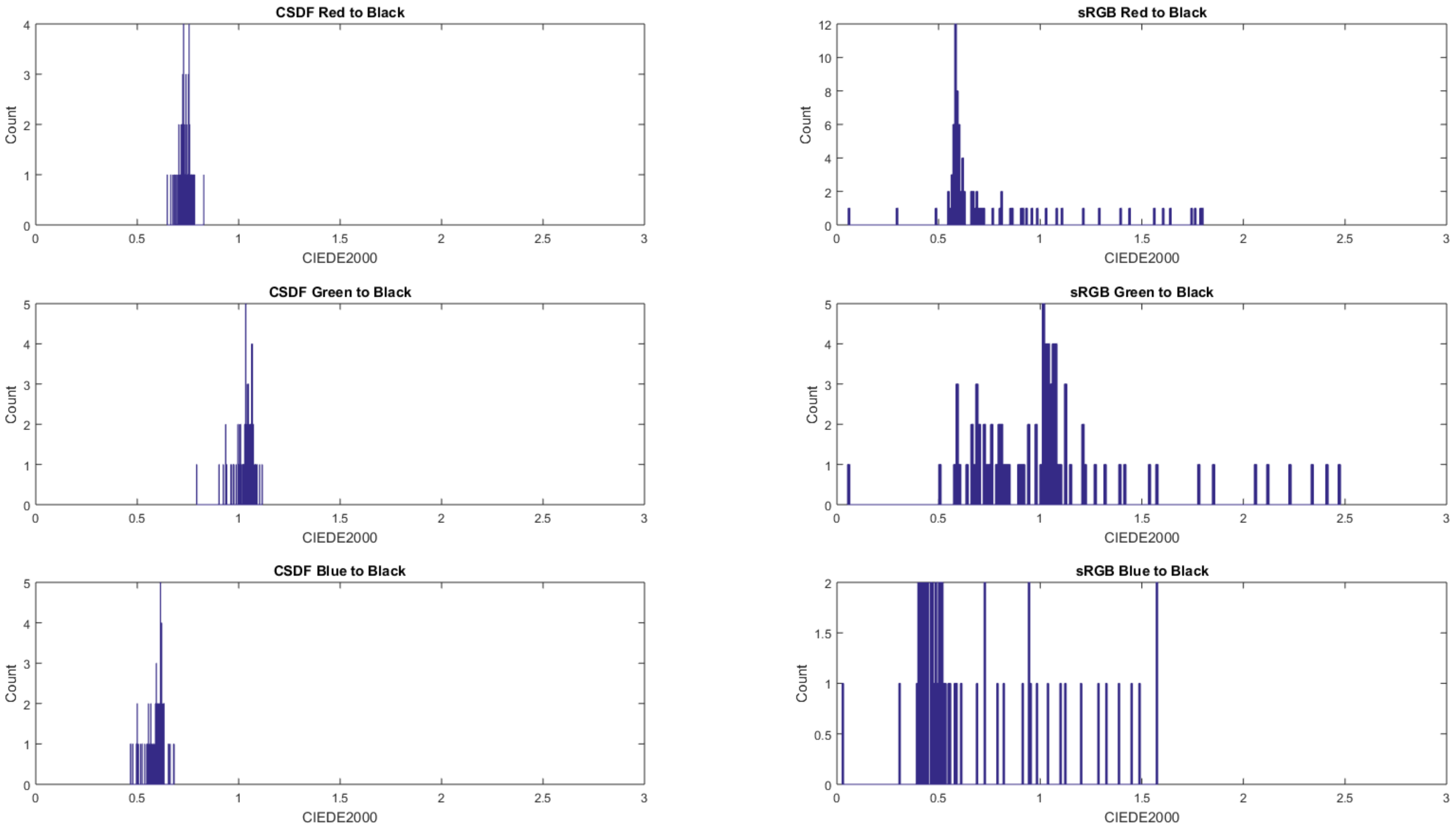
sRGB calibrated display

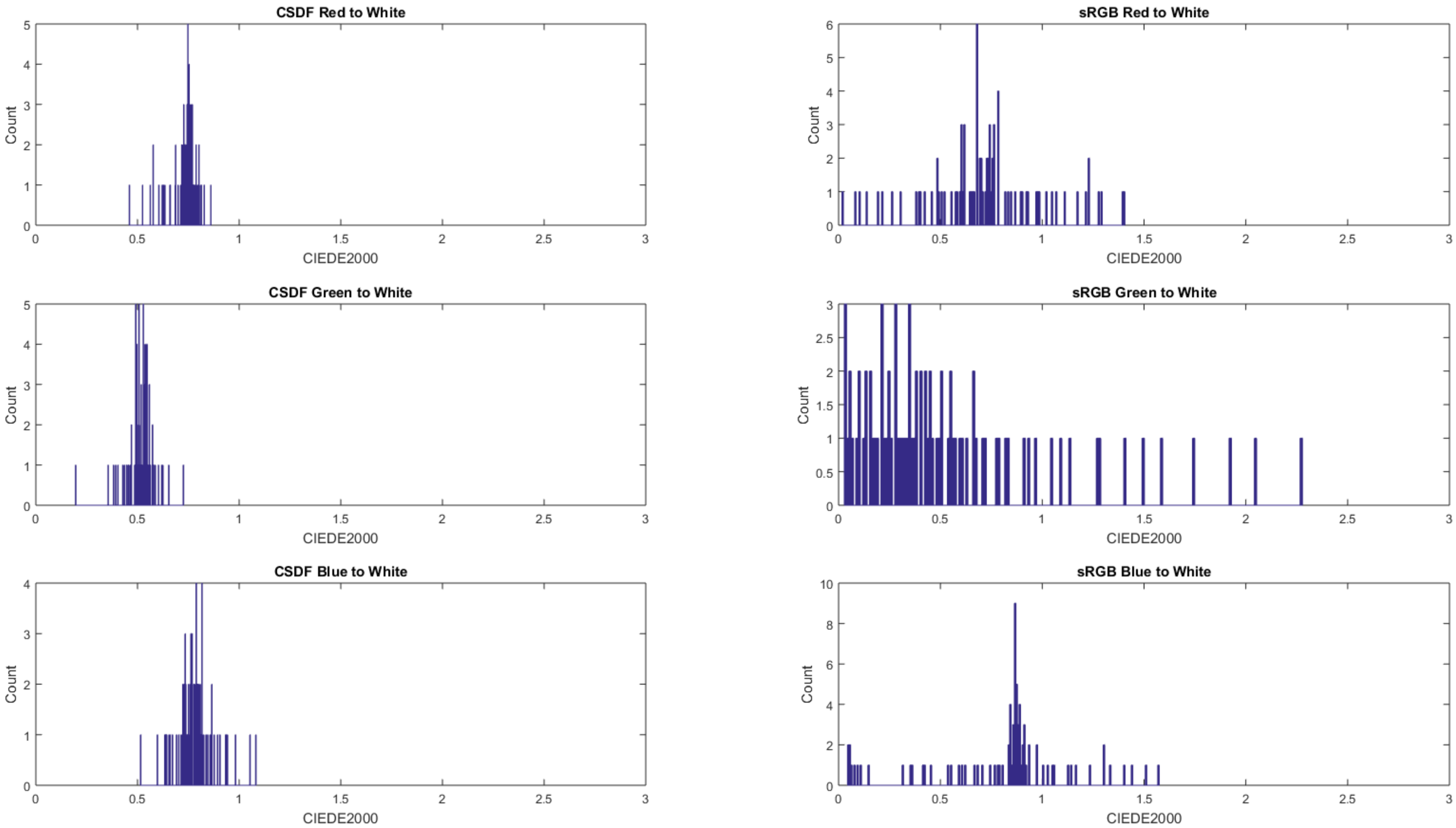
NOTE At this stage no ICC profiling has been done – the calibration is achieved using the tables available in the display

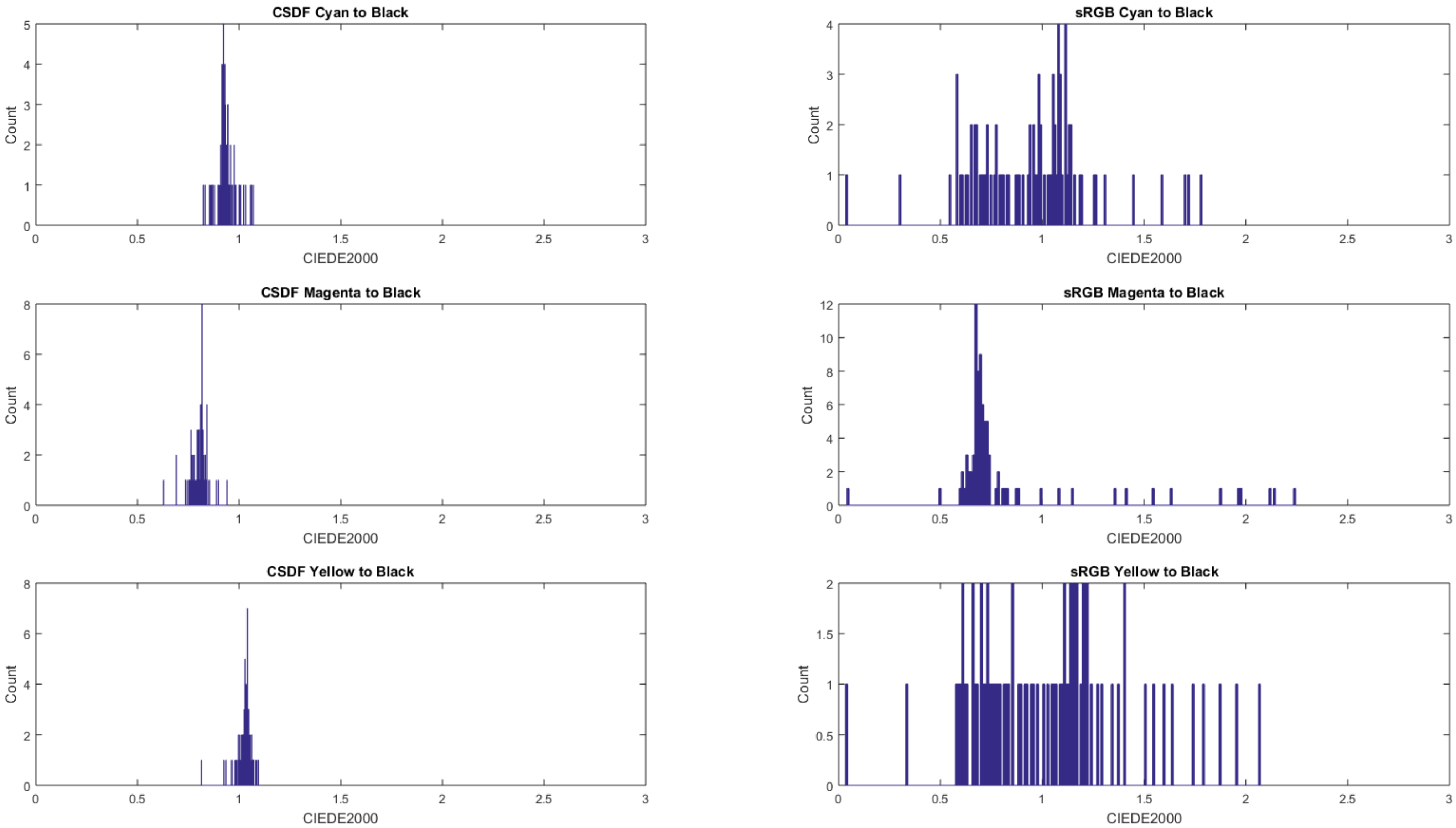
Example – same display calibrated to sRGB and CSDF



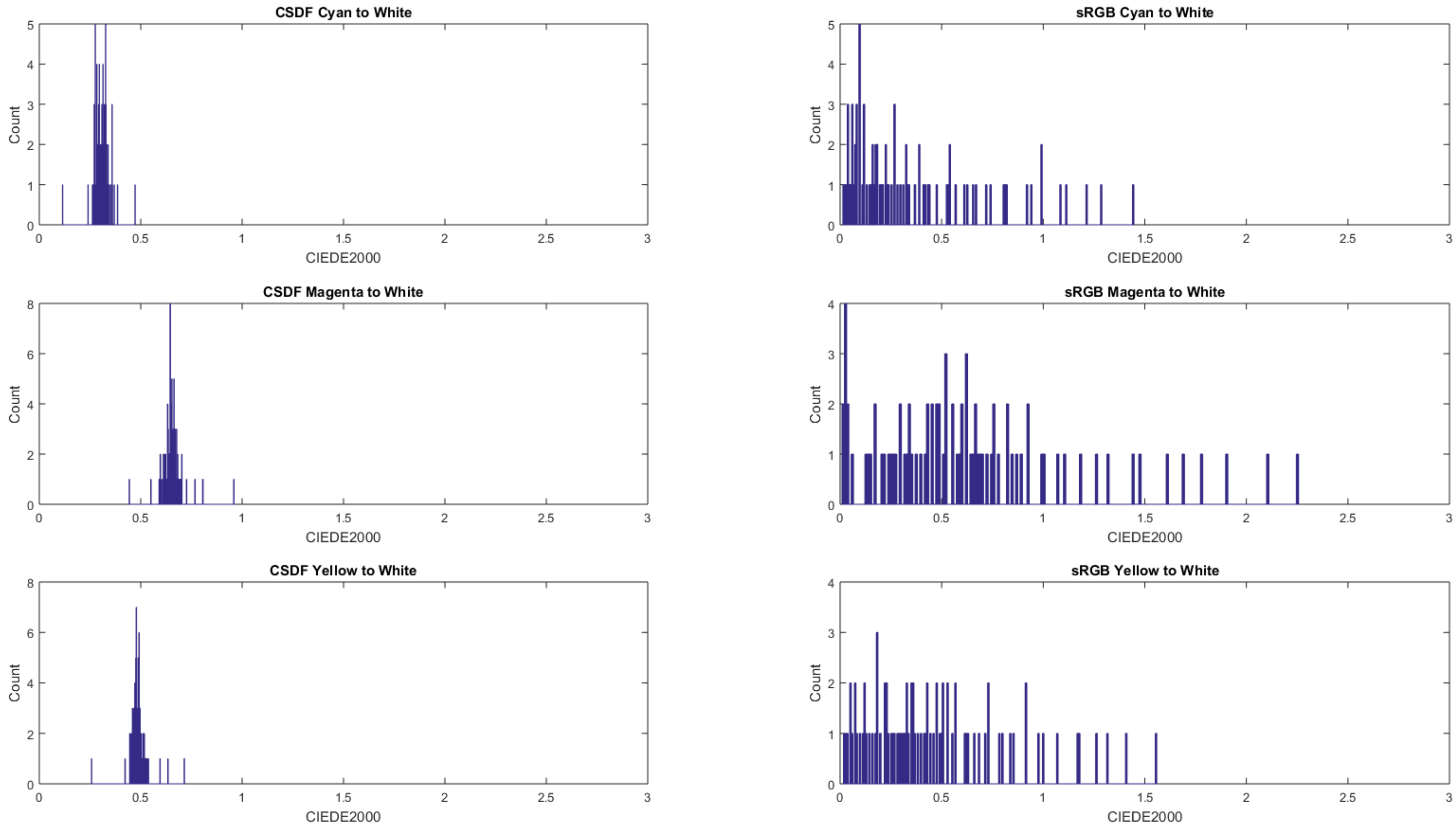
- CSDF white point ‘Clearbase’ ~9300K
- sRGB white point D65


CSDF Red to Black
Count
CIEDE2000
sRGB Red to Black
Count
CIEDE2000
CSDF Green to Black
Count
CIEDE2000
sRGB Green to Black
Count
CIEDE2000
CSDF Blue to Black
Count
CIEDE2000
sRGB Blue to Black
Count
CIEDE2000


CSDF Red to White
sRGB Red to White
CSDF Green to White
sRGB Green to White
CSDF Blue to White
sRGB Blue to White
Count
CIEDE2000
0
0.5
1
1.5
2
2.5
3



CSDF Cyan to Black
sRGB Cyan to Black
CSDF Magenta to Black
sRGB Magenta to Black
CSDF Yellow to Black
sRGB Yellow to Black
Count
CIEDE2000
0
0.5
1
1.5
2
2.5
3


CSDF Cyan to White
sRGB Cyan to White
CSDF Magenta to White
sRGB Magenta to White
CSDF Yellow to White
sRGB Yellow to White
Count
CIEDE2000
0
0.5
1
1.5
2
2.5
3

Pseudo colour palettes

- Many possible pseudo-colour palettes possible
  - Generally defined as RGB with evenly spaced steps in primary or secondary colours
  - Little work has any work been done to identify commonly used colour palettes
- DICOM part6.B Well-Known Color Palettes
  - Hot Iron, PET, Hot Metal Blue, PET 20 Step
- Effect of color visualization and display hardware on the visual assessment of pseudocolor medical images, Silvina Zabala-Travers, Mina Choi, Wei-Chung Cheng and Aldo Badano, Med. Phys. 42, 2942 (2015); http://dx.doi.org/10.1118/1.4921125
  - Rainbow ("jet"), a heated black-body ("hot"), gray ("gray")

Pseudo colour comments and open issues

- DICOM currently specifies the use of sRGB to display pseudo colour which does not ensure consistent perceptual spacing between colours
  - See part 6 Annex B
- None of the ICC rendering intents can maintain perceptual colour separation
- Relationship to dRGB (aka mRGB) to be clarified (see next slide)

Relationship between CSDF and dRGB

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} < $\frac{1}{4}$ L_{min}	L_{amb} < [$\frac{1}{4}$, $\frac{2}{3}$] L_{min}

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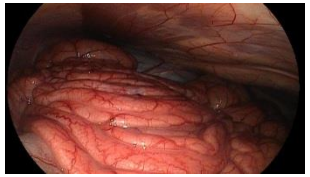
CSDF is one possible colour gamut definition

This topic is still under discussion in ICC MIWG and AAPM TG196

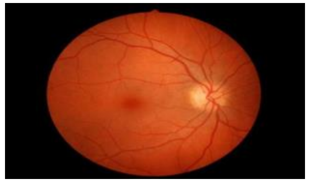
Medical images

Color

Digital Pathology
Whole Slide Imaging



Endoscopy /
Laparoscopy



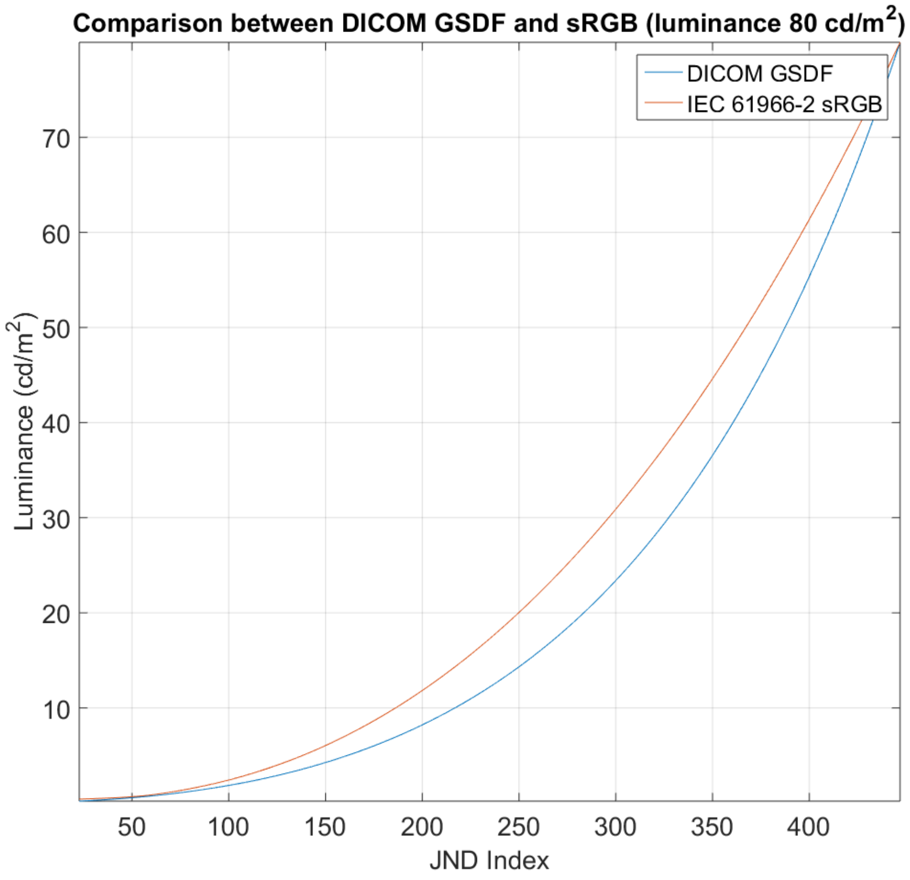
Ophthalmology

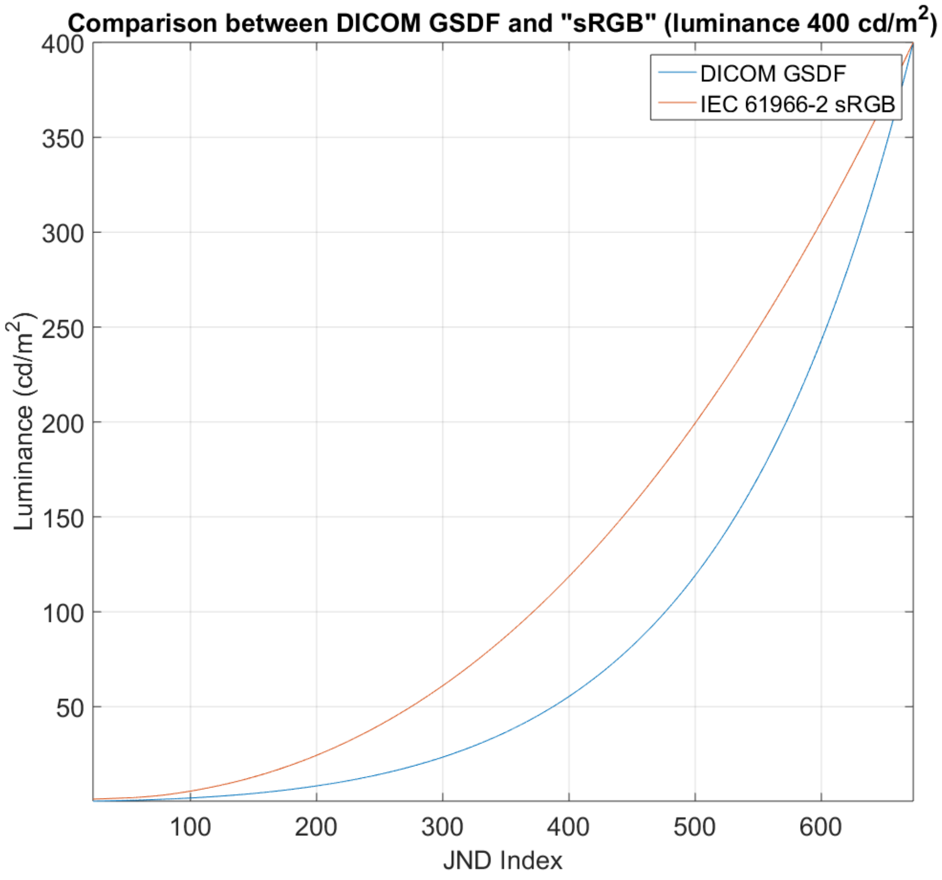
Medical
Photography

Two categories of colour image

- sRGB
  - Examples are endoscopy, laparoscopy, medical photography
  - Probably the majority of ‘true colour’ medical images
  - Can be presented directly on a display calibrated to sRGB without colour management
  - Requires colour management when display calibrated to GSDF
- Images with associated ICC Profile
  - Examples are digital pathology, petri dish imaging, medical photography
  - DICOM requires an ICC Profile for colour images:
    - “The ICC Profile Module shall be present for color images. If the color space to be used is not calibrated (i.e., a device-specific ICCInput Profile is not available), then an ICC Input Profile specifying a well-known space (such as sRGB) may be specified.” *DICOM PS3.3 2015b, A.77.4.3 ‘ICC Profile Module’*

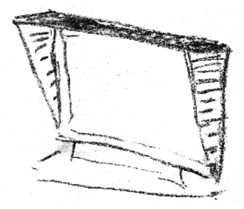
DICOM GSDF compared to sRGB



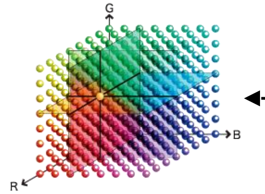


Does calibration to CSDF improve ICC Profiling?
The CSDF calibration should result in substantially more distinguishable colours.

Proposed future work



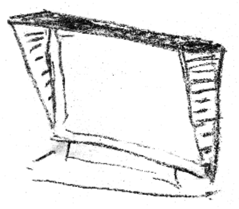
- Neutral scale = GSDF
- R, G and B primaries = sRGB
- *Pairs of neighbouring RGB triplets have the same CIEDE2000 colour difference*



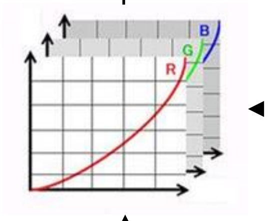
CSDF
cLUT

RGB

CSDF calibrated display



- R, G and B primaries = sRGB



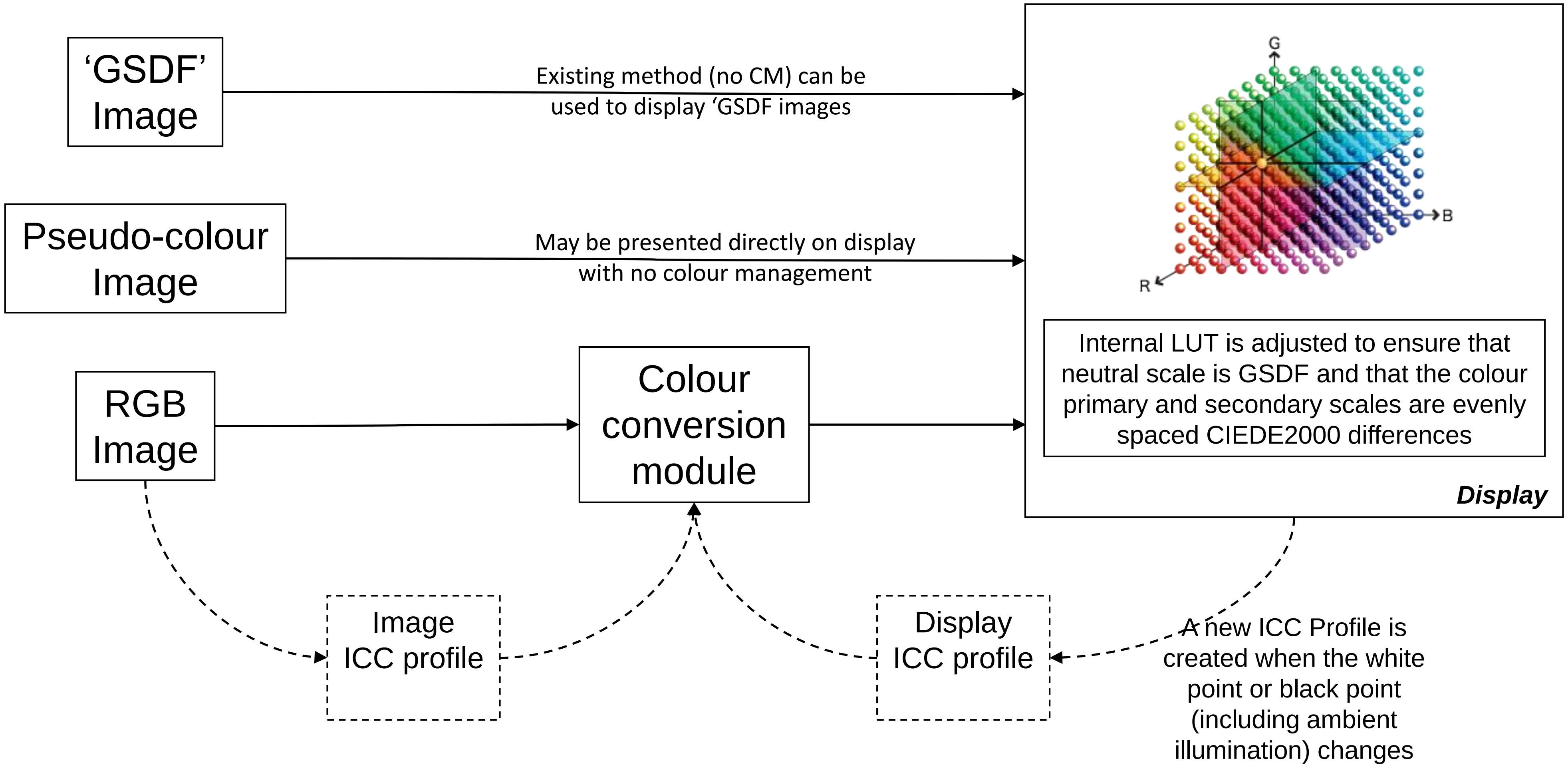
sRGB
1-D LUTs

RGB

sRGB calibrated display

NOTE At this stage no ICC profiling has been done – the calibration is achieved using the tables available in the display

Display of medical images



Suggested work

- Test whether CSDF calibration results in a measurably larger number of distinct colours
  - Verified for primaries and secondary colour scales
  - May depend on the choices made for mapping of colours in the interior of the display gamut - define objectives for mapping of these colours
- Test whether using CSDF calibration and ICC colour management results in a measurably larger number of distinct image colours being displayed
- For both cases demonstrate that there is a diagnostic benefit
- Resolve white point issue – radiology imaging traditionally uses BlueBase or ClearBase which may not be the best choice for the display of colour images

- Work is currently being done in some of these areas – perhaps it would be helpful to provide pointers to this work on the ICC MIWG web site

Discussion