Medical Imaging Working Group

Adobe Systems Incorporated, Corporate Headquarters
345 Park Ave, East tower
San Jose, CA 95110 USA
13 October 2015

Craig Revie, MIWG chair, opened the meeting at 13:30 and introduced the agenda for the meeting as follows:

1. Using the ICC framework for colour calibration of medical displays
2. Calibration of medical displays using ICC profiles
3. Estimation of errors associated with film-based calibration

Summary and status of each area of activity in MIWG:

4. Whole slide imaging
5. Medical photography guidelines
6. Calibration materials for ophthalmology
7. Petri dish imaging
8. Skin imaging

1. Using the ICC framework for colour calibration of medical displays

Dr Tom Kimpe presented activities to date on display calibration [see attached]. Visualisation of greyscale images on colour displays had been discussed in August, and the current goal was to extend this to colour images. A new draft of a proposed recommendations document had been circulated [see attached], and he invited feedback so that the document can be finalised.

Dr Kimpe showed the calibration framework, in which data is converted to the PCS using a CSDF profile. From feedback received improvements had been made to the profile, full details are in the draft document. New results showing the errors arising from different LUT sizes and gamma values had been included. The importance of using 10-bit data was clear as it minimises calibration error; for LUT size, there was only marginal improvement with a grid spacing of over 30. Accurate modelling was also important.

Dr Kimpe showed the draft recommendations that are in the document, and asked for feedback by October 19.

Dr Michael Flynn noted that a nominally 10% error was shown. DICOM Part 14 shows how to compute this for grayscale data, and he asked how it was being done for colour. Dr Kimpe responded that an analogous method was used, and was explained in part 5.2 of the document. Dr Flynn stated that AAPM TG 18 had developed ACR 2012 professional guidelines which set 10% as the tolerance for primary diagnostic displays,

and 15-20% for review and clinical displays. The 15% figure was based on what is achievable, and on the visibility of test images. Calibration is less critical for colour than for grayscale.

The meeting agreed that the document could be a candidate for an ICC White Paper, and Phil Green undertook to advise on the process.

Dr Po-Chieh Hung observed that pseudo-contours could be critical for medical imaging, and asked if it had been evaluated in all directions. Dr Kimpe agreed that smoothness in the profile was important, and Phil Green undertook to provide references on papers published on this topic.

Dr Kimpe agreed to make calibration targets used in the work available to the group.

It was agreed that a CMM should use 10 bits, and this can be achieved in a standard CMM. Applications generate 10-bit data, but subsequent processing should use a 10-bit pipeline.

James Vogh noted that getting OpenGL to use 10 bits was not simple, and he was not aware of 10-bit support on OS10. Kimpe stated that it had not been a problem in Windows. It was agreed that this point needed to be clarified, and Mr Vogh and Dr Kimpe agreed to check for Windows, Linux and Mac support. Dr Kimpe also invited further feedback on the document.

2. Calibration of medical displays using ICC profiles

Marc Leppla of Qubyx presented some work on CSDF color calibration through ICC profiles [see attached]. He had worked on colour soft copy presentation state in NEMA and DICOM, and believed that ICC was the key to getting good quality with cheaper devices. He summarised the evolution of display technology.

He proposed alternatives to using CSDF. The first example was a link profile that maps from uncalibrated RGB to a CSDF-calibrated display, with error minimisation in CIEDE2000. True-colour images are displayed using a conventional source and destination profile.

His second example was a profile which transformed grayscale and RGB pseudo-colour data into CSDF. This profile can then be used as a source, and a conventional display profile as the destination.

The advantage of using a link profile is high quality, less errors, and the ability to change between GSDF and CSDF on the fly by swapping profiles. There was no need for hardware LUTs, which tended not to be supported on lower-cost devices. It was possible to have different profiles for different display states.

He also proposed a calibration to the CIELAB L* function, as opposed to a display gamma, as L* was perceptually uniform and would give better discrimination in dark colours.

He would like to continue work on this topic, especially on the link profile idea. When implementing the recommendations in the calibration guidelines, it would be easier to achieve the tolerances with a link profile.

There was a consensus in agreement with these ideas, although the L* vs. GSDF aspect would need more discussion. Dr Kimpe noted that this has been discussed extensively in DICOM, and in his view it was important to support the common case where pseudo-colour is presented as a mix of gray and colour, where the gray must be GSDF.

3. Estimation of errors associated with film-based calibration

Craig Revie presented an estimation of the calibration error associated with the use of a film calibration target [see attached]. It was often assumed that training data should be based on actual reflectances, and he

had done some analysis to test the assumption on H&E stains. He showed the difference between stained tissue and the closest patch on a film target, and provided an example of film and stained colours with the same RGB values and a maximum difference of 5 in CIEDE2000. The Eosin stains were outside the film gamut, and had sharper spectra. He concluded that estimating the colour of the stains from the scanner RGB values would inevitably have a large uncertainty. He invited further input on the topic. Eric Walowit and Jack Holm undertook to provide input on the errors arising from different types of training set.

4. Whole slide imaging

Mr Revie gave an update on the Sierra project [see attached]. FFEI have now developed a calibration slide, in addition to the calibration assessment slide discussed in previous meetings. A LUT-based profile using this slide has errors of less than 5 in CIELAB ΔE^*_{ab}. H&E stains are the priority for the calibration slide owing to their widespread use, and it was not possible to minimise all errors. FFEI will make and send a profile to each evaluator of the slide, based on their scanned image of it, and vendors are asked to assess the reproducibility of their calibration results.

FFEI are still seeking a manufacturer of the biopolymer-based calibration slide. However, an important outcome is that all participating vendors have improved their calibration methods and reduced variability by using the calibration slide.

5. Medical photography guidelines

Phil Green provided a summary of the Medical Photography draft guidelines on behalf of John Penczek, the document editor [see attached]. The current draft was circulated in April 2015; it was based on current good practice in professional photography, and on commercially available equipment. It covered DSC capture, not other modalities. One finding was that ICC was only realistic option for open-source calibration.

6. Calibration materials for ophthalmology

Dr Green presented a status report on the colour eye project on behalf of Christye Sisson [see attached]. The goal was to reduce variability in retinal fundus imaging by establishing calibration methods. The project is now in Phase III, where the calibration target is being modified to provide a curved surface, a modified model eye with low power optics used, more extensive camera testing is being undertaken, and a final feasibility report prepared.

7. Petri dish imaging

Dr Green presented a summary of work on Petri dish imaging on behalf of Jérémie Pescatore [see attached]. Goals included building a database of spectral reflectance and transmittance data, standardizing measurement methods, and developing or adopting appropriate standards for management of display configurations.

8. Skin imaging

Dr Green showed an update on skin imaging on behalf of Kaida Xiao [see attached]. Dr Xiao is working on skin reflectance measurement at University of Liverpool, UK, to develop skin reflectance estimation and reproduction methods (e.g. for prosthetics). At the University of Science and Technology, Liaoning, he is working on a skin spectra image database based on camera RGB image and spectra reflectance estimation. A psychophysical experiment is also in plan to investigate the naturalness of facial images using the image database, and to evaluate the performance of different spectral estimation algorithms.

Due to the lack of time, two items were deferred to the next meeting:

- Assessment of CSDF colour calibration model
- Review of Action items from previous meeting

Mr Revie thanked all the attendees for their participation. The meeting closed at 4:00pm.

Action items

MIWG-2015-26 Provide feedback to Kimpe on display calibration recommendations by October 19 (all)

MIWG-2015-27 Proceed to finalise document and submit for approval as ICC White Paper (Kimpe)

MIWG-2015-28 Provide template and information on WP approval process to Kimpe (Green)

MIWG-2015-29 Send references on evaluation of profile smoothness to Kimpe (Green)

MIWG-2015-30 Make assessment targets available to group (Kimpe)

MIWG-2015-31 Clarify support for 10-bit display pipeline on Mac OS10, Windows and Linux (Vogh and Kimpe)

MIWG-2015-32 Add details of how to achieve CSDF calibration using ICC Profiles to White paper being developed by Tom Kimpe (Marc Leppla)

MIWG-2015-33 Continue to discuss L* vs sRGB and GSDF calibration (all)

MIWG-2015-34 Provide input on calibration errors using different types of training sets (Holm, Walowit)

MIWG-2015-35 Send ICC profile based on Sierra calibration to each evaluator (Revie)

MIWG-2015-36 Evaluate reproducibility of WSI calibration (vendors)

International Color Consortium

ICC Medical Imaging Working Group

San Jose

13th October 2015

ICC: EVENTS:

All ICC Events

2016

Display & 3D print, Taipei 2016

2015

iccMAX Webinar April 22

Medical Imaging Experts Day Mar 4

Other ICC Medical Imaging meetings

NPES-ICC Color Management Conference Feb 12

Upcoming ICC Meetings

2014

ICC Medical Imaging Working Group

The Working Group arose out of the Summit on Color in Medical Imaging held in Silver Spring, Maryland in May 2013. It exists to enable and promote the correct and effective use of ICC color management for medical imaging.

Current activities:

- Calibration slide for histopathology
- Medical RGB color space - mRGB / dRGB
- Color eye model
- Best practices for digital color photography in medicine
- Colour support for mobile devices
- Framework for multispectral imaging
- Petri plate calibration
- Imaging and reproduction of skin
- DICOM camera raw support and EXIF tags
- Open source reference implementation
- Best practice papers for colour in DICOM

Summary of all MIWG **work items**

Upcoming MIWG meetings

Date	Location	Topic
13 Oct 2015	San Jose, CA	Full WG meeting

Details of meetings will be posted when available. If you wish to participate in a meeting, please contact the **ICC Secretary**

SEARCH ICC : GO

Got a question about ICC Profiles or colour management?

Ask Phil...

ICC: LIVE TOPICS:

iccMAX

Research fund

ICC Medical Imaging Working Group

Display calibration

New PRMG-based exchange profile for digital print

Profiling tools

ICC Profile Registry

sRGB profiles

ICC user forum

Membership benefits

What is an ICC Profile?

Introducingé the UFO camera

Back in the 1950s, there were so many UFO sightings reported each year that the government finally decided enough was enough. The Air Force introduced the Flying Saucer Camera, a special camera with two lenses designed to identify the source of strange lights. One lens took a normal photo while the other separated light into colors so that the origins of the light would be obvious. It was not even necessary to use colour film.

Modified Stereocrafters Videon 35mm stereo camera, see:
http://books.google.com/books?id=yS0DAAAAMBAJ&pg=RA1-PA227#v=onepage&q&f=false

ICC MIWG Working group meeting

Tuesday 13th October, 13:00-15:30

- **1. Using the ICC framework for colour calibration of medical displays** Tom Kimpe
- **2. Calibration of medical displays using ICC profiles** Marc Leppla
- **3. Estimation of errors associated with film-based calibration targets** Craig Revie
- **Summary and status of each area of activity in MIWG**
  - —4. Whole Slide Imaging Craig Revie
  - —5. Medical photography guidelines (John Penczek)
  - —6. Calibration materials for Ophthalmology (Christye Sisson)
  - —7. Petri Dish Imaging (Jeremie Pescatore)
  - —8. Skin imaging (Kaida Xiao)

Deferred

- **Assessment of CSDF colour calibration model** Craig Revie
- **Review of action items**

ICC Medical Imaging Working Group meeting

“Using the ICC framework for colour calibration of medical displays ”

Tom Kimpe
Barco NV
(tom.kimpe@barco.com)

October 13th 2015

San Jose, CA, USA

Summary of the activities so far (1)

- Collection of test images and bench testing data for a range of displays
- General architecture proposal for calibration of medical color displays in ICC context

- How can we ensure consistent and accurate greyscale representation of medical images on color displays?
  => Draft recommendations for *greyscale* images (GSDF) on color displays was approved on August 4th 2014 by the MIWG

Summary of the activities so far (2)

- Between August and now a lot of additional work was done related to colour visualization of medical images
- The recommendations document was updated to:
  - Take into account colour visualization as well
  - Profile structure has been improved a lot based on comments of Phil Green & Craig Revie
- The new document was distributed by email to the entire ICC MIWG on october 8th 2015 and feedback was requested

Goal of today's meeting

- Present a short powerpoint that summarizes the recommendations document

- Collect feedback from the ICC MIWG on this document

Calibration framework

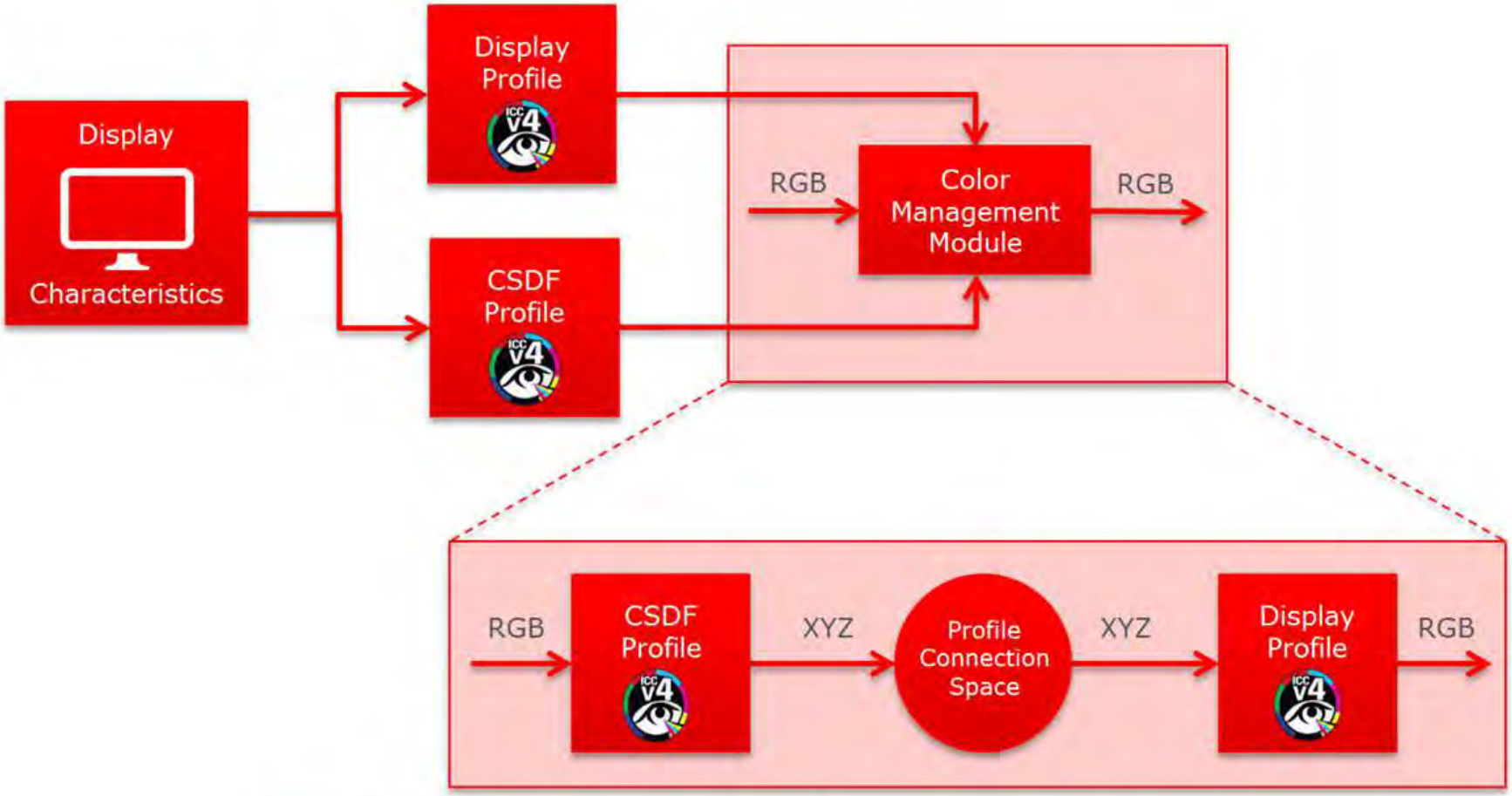


Figure 5: Workflow of ICC based CSDF display calibration.

Profile specifics

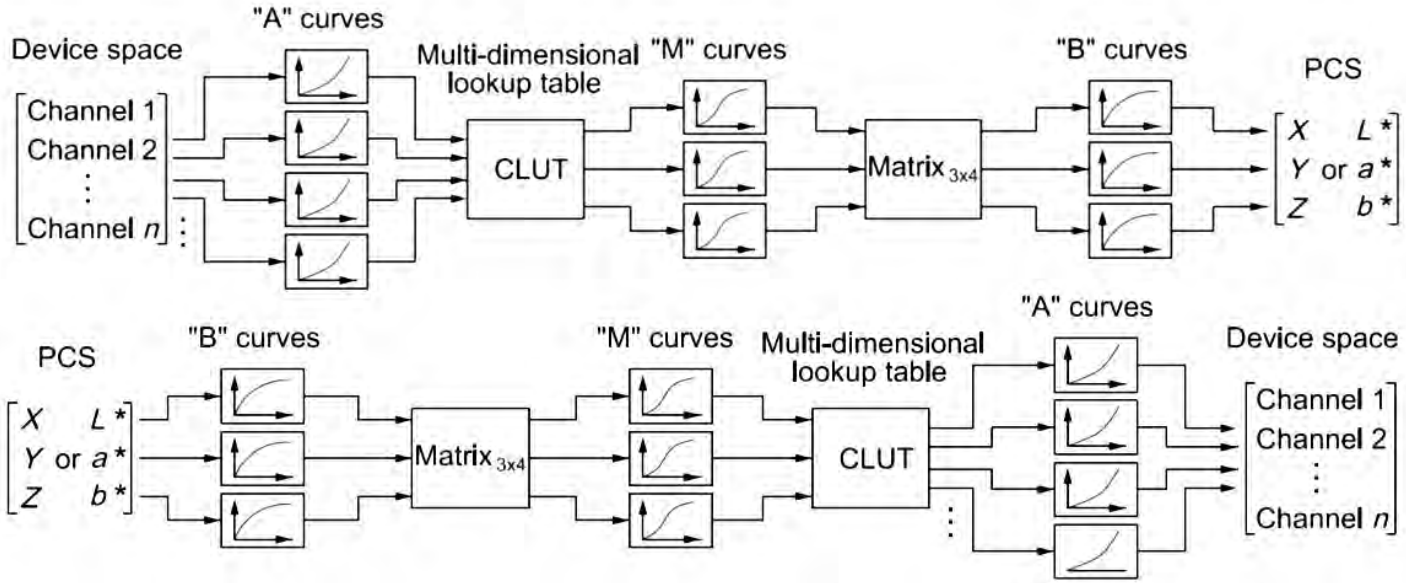


Figure 10: Device-to-PCS and PCS-to-Device conversion workflows for LUT based profiles. The different elements arround the Color LUT (CLUT) can be used to create a nonlinear repartition of the input values of the LUT, or set to identity.

Profiles were constructed using the XYZ PCS.

- A-curves are unused in both Device-to-PCS and PCS-to-Device conversions and were thus set to be identity tone curves.
- CLUT stages are used for RGB-to-RGB conversions. The tables may contain individual point corrections to make the profile more faithful to the display it represents.
- M-curves are used to apply inverse RGB companding in Device-to-PCS conversion and RGB companding in PCS-to-Device conversion. This handles the RGB-XYZ non linearity and makes RGB linear.
- The matrix is used to finish the linear RGB-to-XYZ conversion and thus contains RGB reference primaries as XYZ values, written in column order. For encoding reasons, these values are all divided by 2.
- B-curves, as A-curves, were unused in both tags and were set to identity curves.

Bit depth and CLUT size

Table 11: CSDF color compliance obtained by using different display models and different size of CLUT in the source profile.

Destination Profile	Source profile LUT size	CSDF max deviation	CSDF max deviation 10 bits	CSDF max deviation 8 bits
sRGB	11	10.5925%	12.2006%	15.3341%
	18	1.8321%	2.6243%	9.0303%
	33	2.8383%	2.9012%	9.4645%
	65	1.9395%	2.6244%	9.0303%
Gamma 3.5	11	10.5638%	10.3971%	10.2444%
	18	1.8040%	2.1415%	7.4469%
	33	2.8245%	3.3183%	7.4469%
	65	1.9400%	2.1415%	7.4469%
Gamma 2.2	11	10.5470%	12.0502%	21.5339%
	18	1.7700%	1.6746%	7.5699%
	33	2.7996%	2.0485%	7.5699%
	65	1.9292%	1.6773%	7.5699%
Gamma 1.8	11	10.5730%	13.7676%	19.4952%
	18	1.7920%	3.2202%	14.7574%
	33	2.7895%	4.0300%	14.7572%
	65	1.9337%	3.2202%	14.7574%
DICOM	11	10.5868%	10.7014%	13.1294%
	18	1.8044%	2.0298%	7.3060%
	33	2.8373%	3.2150%	7.3060%
	65	1.9508%	1.8503%	7.3060%

CLUT size

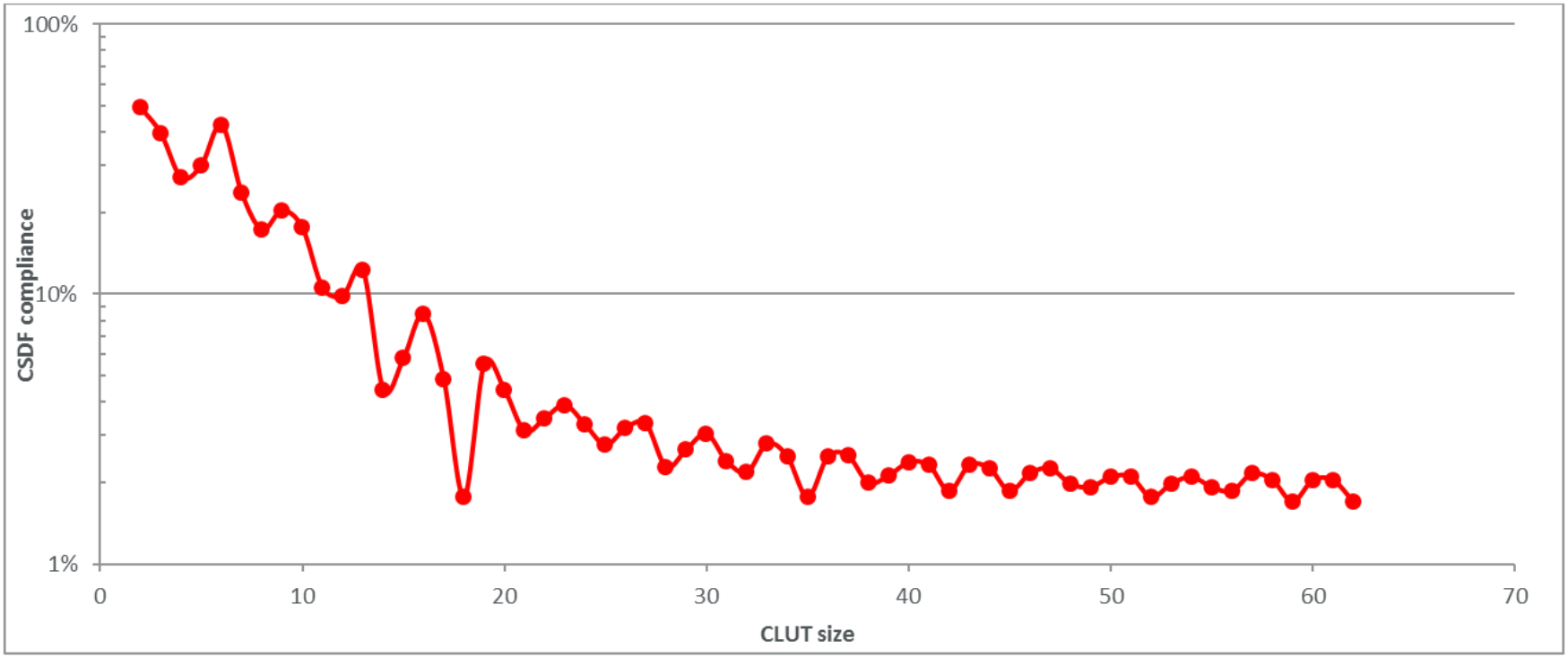


Figure 12: Observed CSDF compliance as a function of the source profile CLUT size when used with $600\ cd/m^2$ with contrast ratio of 1000:1 in logarithmic scale on vertical axes.

Impact of inaccurate display characterization (1)

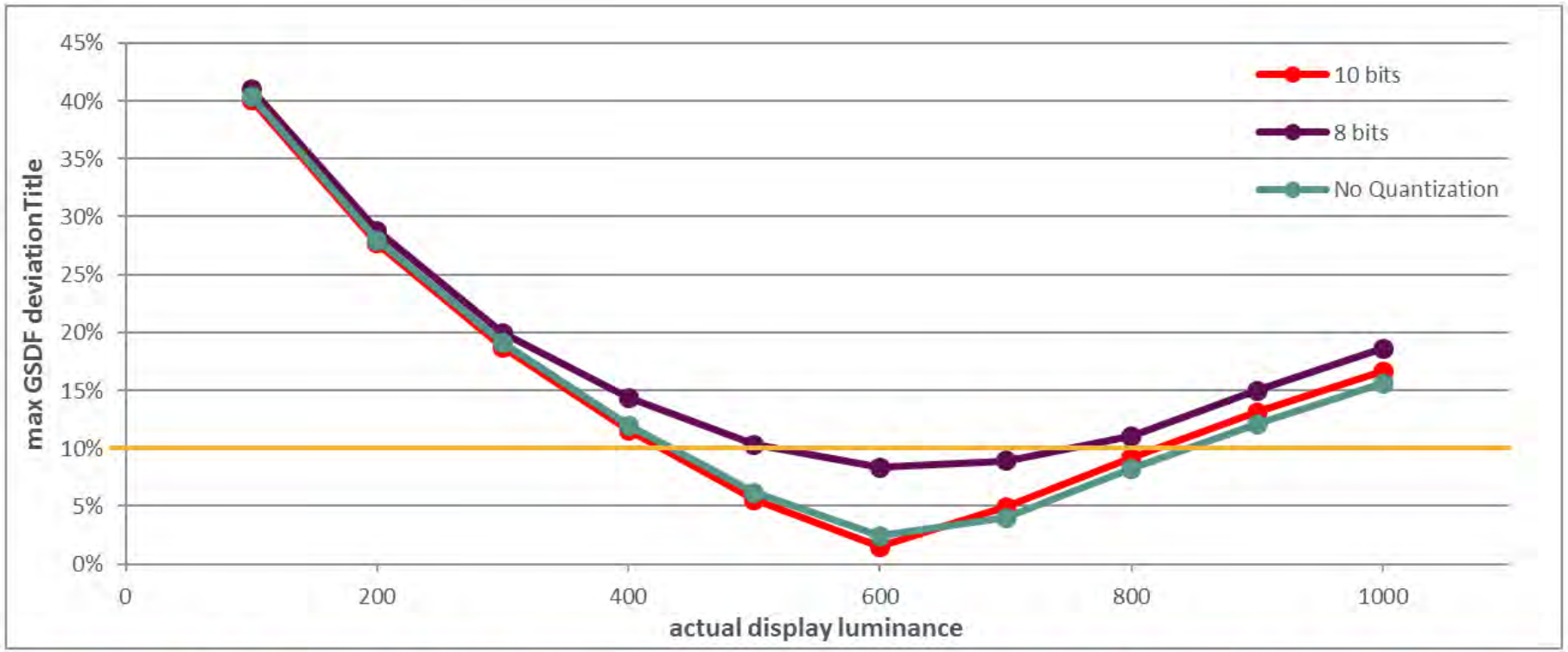


Figure 13: Influence on GSDF compliance of Luminance mismatch between a sRGB profile describing a luminance of $600\ cd/m^2$ relatively to the actual display.

Impact of inaccurate display characterization (2)

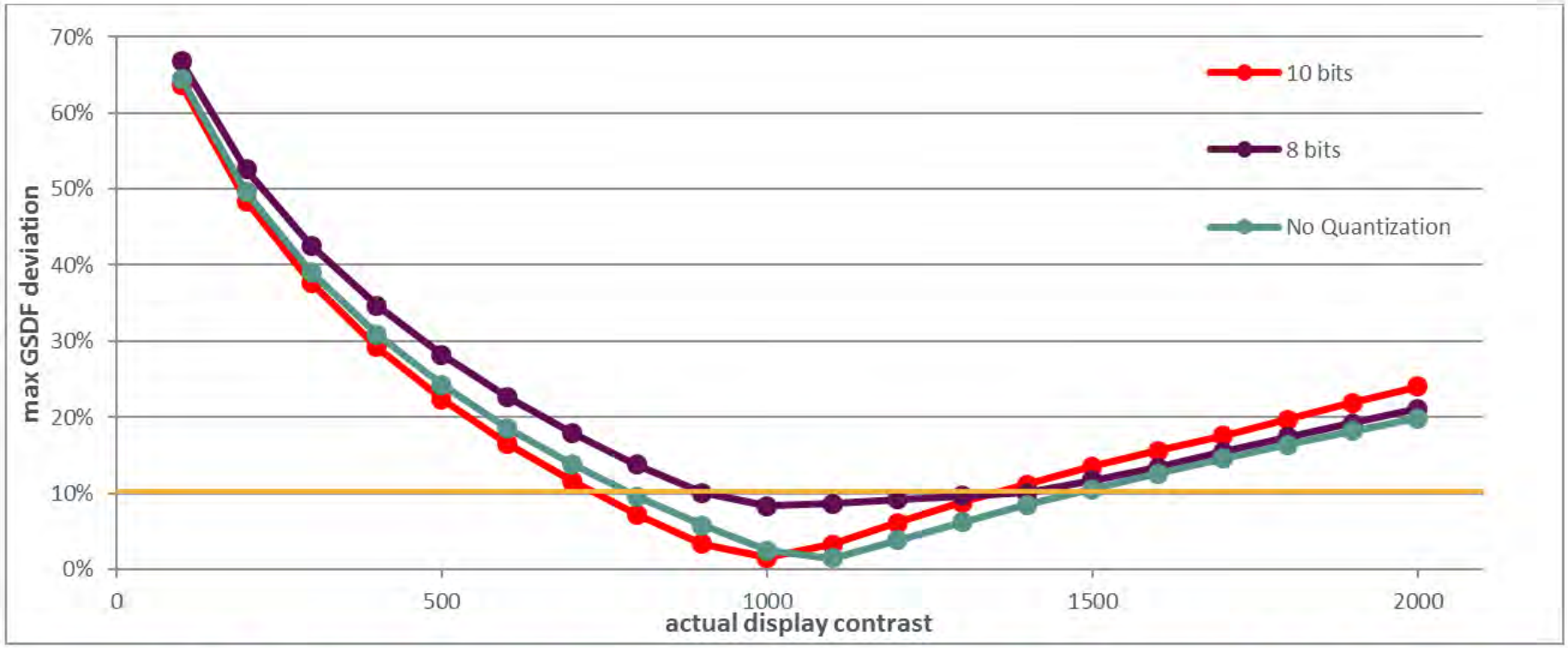


Figure 16: Influence on GSDF compliance of contrast mismatch between an sRGB profile describing a 1000:1 contrast ratio relatively and the actual display on GSDF deviation.

Impact of inaccurate display characterization (3)

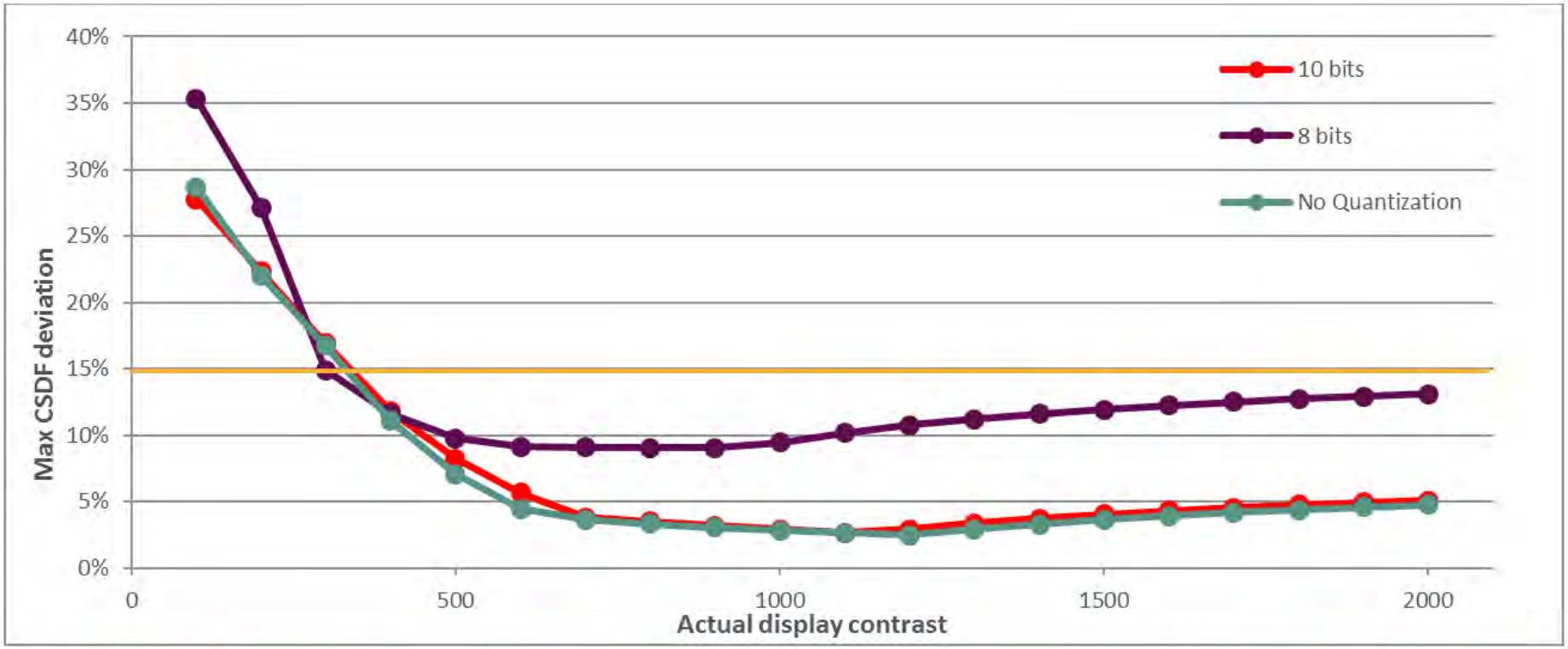


Figure 17: Influence on CSDF compliance of contrast mismatch between an sRGB profile describing a 1000:1 contrast ratio relatively and the actual display on CSDF deviation

Impact of inaccurate display characterization (4)

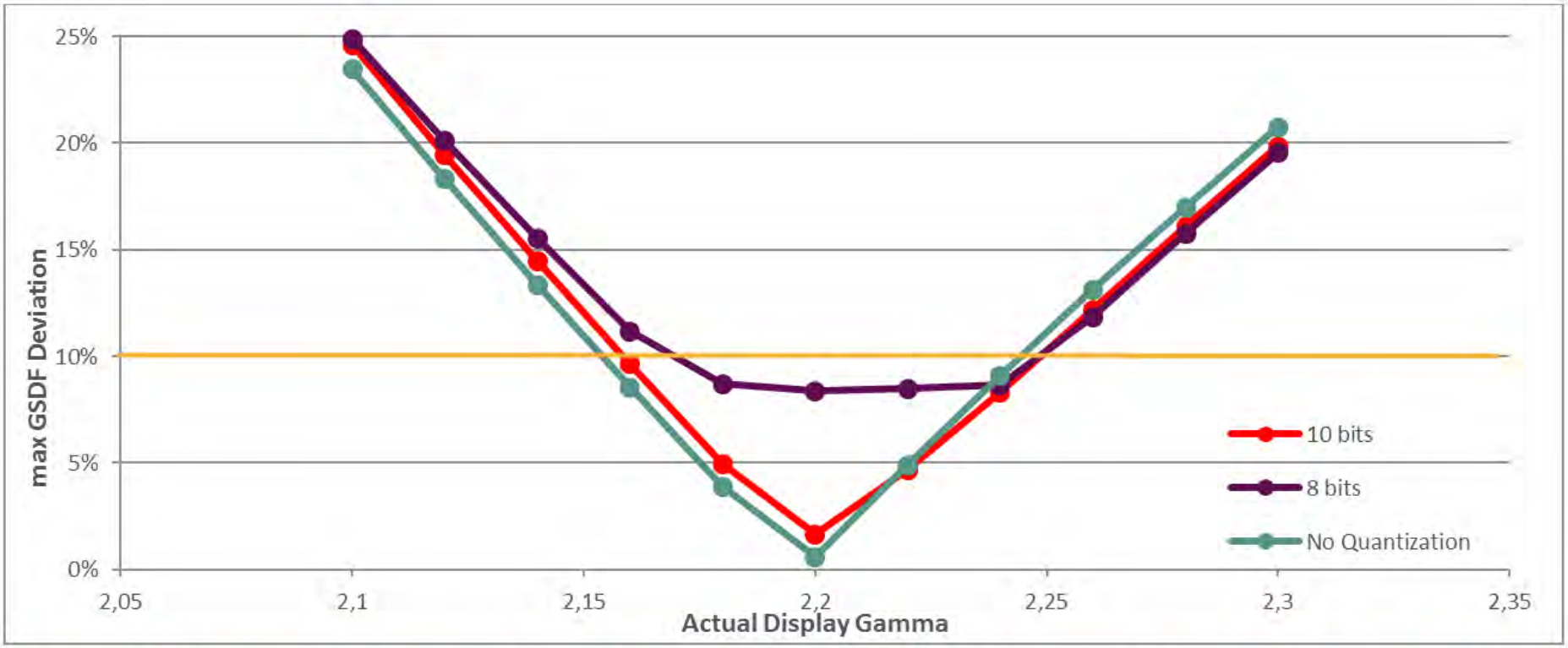


Figure 18: Influence of display function mismatch between a gamma2.2 profile and the actual display on GSDF

Impact of inaccurate display characterization (5)

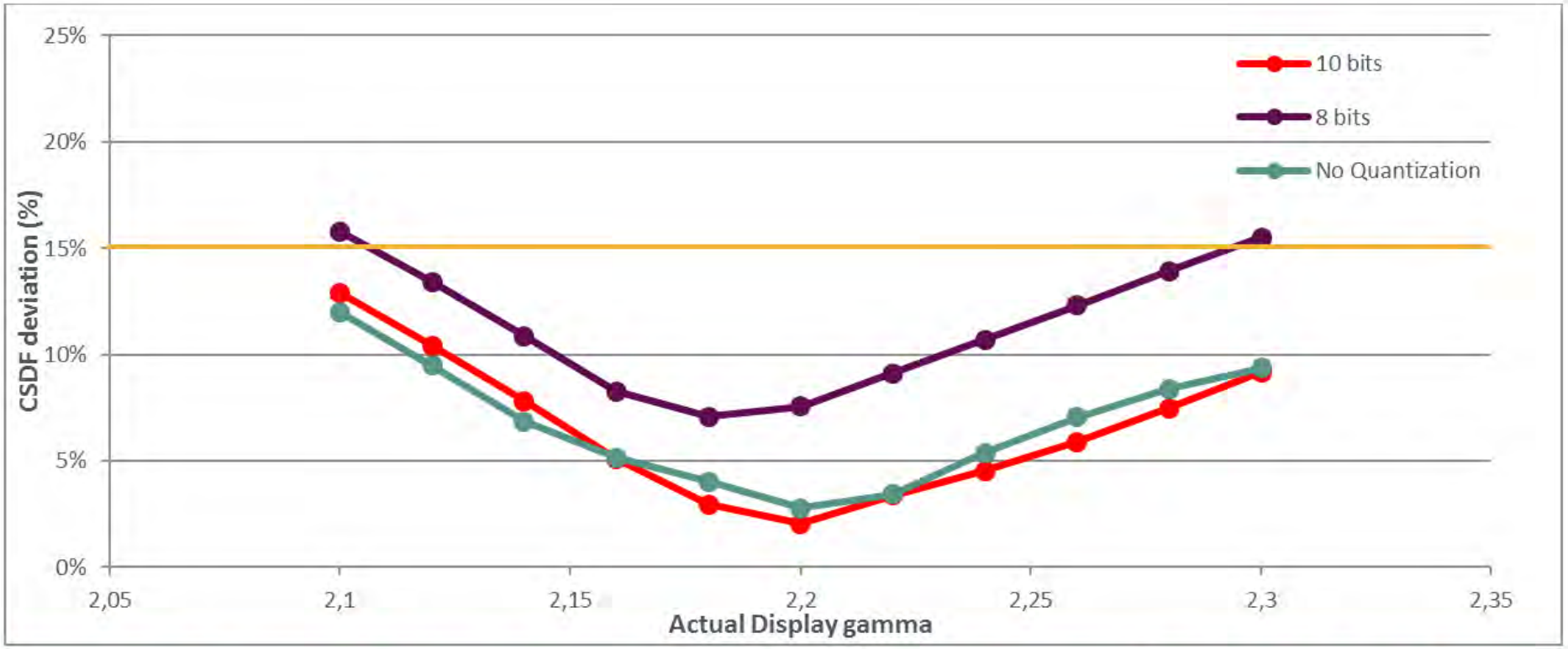


Figure 19: Influence of display function mismatch between a gamma2.2 profile and the actual display on CSDF

Impact of inaccurate display characterization (6)

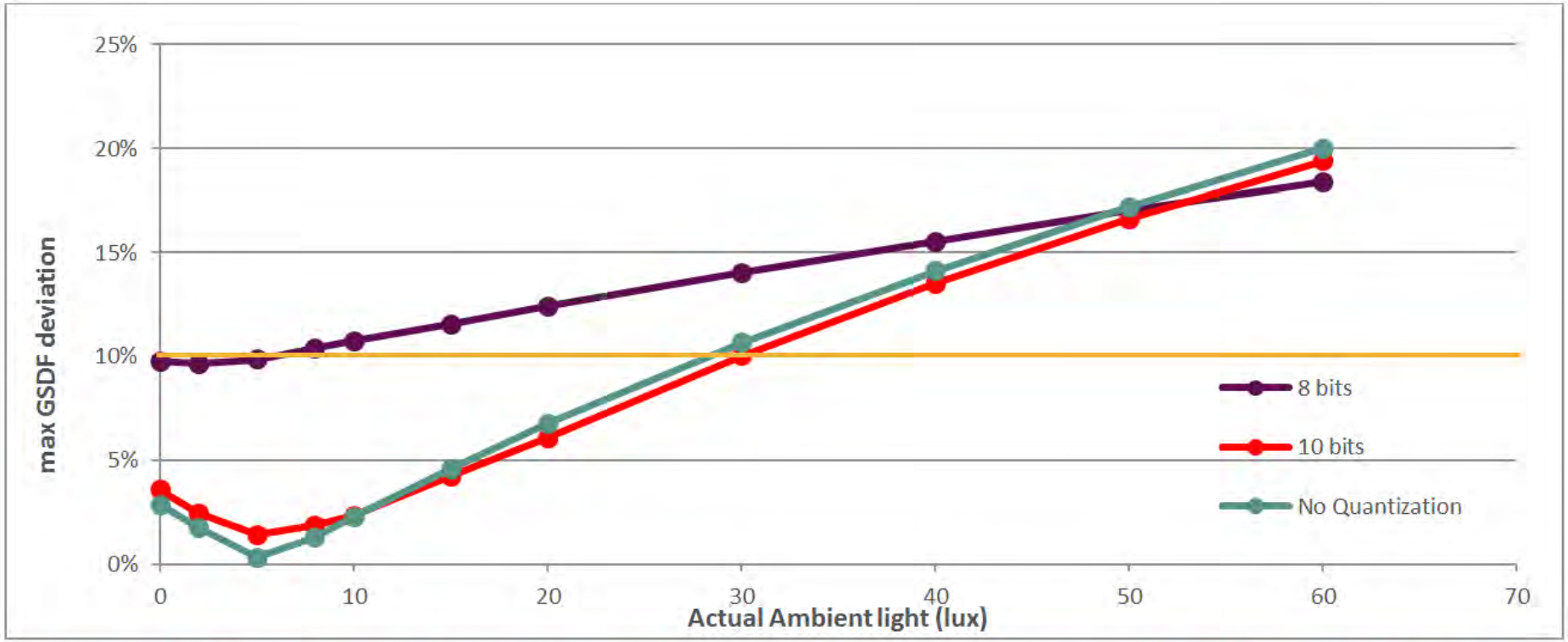


Figure 21: Effect of the ambient light on DICOM GSDF compliance when ICC profiles used for calibration are built for an illumination of $5lux$ with an $18 * 18 * 18$ color LUT

Recommendations (1)

For non-calibrated displays, the following recommendations are provided with the goal to stay within 10% tolerance of the DICOM GSDF target and the 15% tolerance of the CSDF target:

- System configuration:
  - Only use ICC profiles that have been specifically created for the specific display. Generic profiles do not offer sufficient accuracy, even if the display can be set to a reference state.
  - Every time a display setting is changed (e.g. display luminance or contrast settings), new source and destination profiles need to be created and used.
  - Use at least $10\ bit$ connections from application to software when a most accurate calibration is needed, since $8\ bit$ ones are clearly not enough for these use cases.
  - Display luminance and contrast should be stabilized to the value given by the profile since luminance and contrast deviations result into reduced calibration accuracy (See Figure 13 and Figure 16).
  - If the luminance cannot be stabilized, a "warming-up" period of $2\ hours$ should be respected before the display can be used. This duration can be adapted to the display manufacturer's recommendations (see Figure 15).

Recommendations (2)

- ICC Profile and CMM:
  - Both source and destination profiles must take the ambient light into account.
  - Both source and destination profiles should be LUT based profiles using XYZ color space as PCS as described in section 3.3.
  - For DICOM GSDF calibration of grayscale display, the use of monochrome profile is possible, and recommended.
  - For Color calibration, the CLUT of the source profile (describing the calibration) must have a size of at least $13 * 13 * 13$ points to be compliant (see Figure 12), but using at least $31 * 31 * 31$ points is recommended for a more accurate calibration. The display profile can be matrix-based, but we recommend using a more accurate LUT-based profile as depicted in section 3.3.
  - Special attention must be given to PCS-To-Device conversion of the Black point. This is critical to achieve an acceptable calibration. See section 6.2.

Recommendations (3)

- Calibration process:
  - The calibration process must be repeated at least every 50 calendar days since typical display behavior changes over time as Figure 14 shows. This means renewing display measurements and regenerating the display profile based on these measurements. More frequent measurements are possible and could guide determining when recalibration is needed.
  - Ambient light must be stable. Otherwise, the calibration process must be repeated several times a day (see Figure 23).

Next steps

- Further feedback can be submitted until October 19th 2015 (tom.kimpe@barco.com)
- Feedback received will be integrated in the recommendations document

- Tom will then distribute the document once more to the entire ICC MIWG
- The document then should be formally approved by the ICC MIWG

Questions?

(tom.kimpe@barco.com)

QUBYX

CSDF color calibration through ICC profiles

possibilities and advantages of a hardware-independent calibration method

Marc Leppla, PhD

PhD University Nice Sophia Antipolis, France

Founded 1996 QUATO sarl, manufacturer and distributor of Scanners, Calibration Software and Displays for the graphics market
Founded 2002 QUBYX, manufacturer of calibration and verification software for the Medical, Graphics and Defence industry.

Current status in NEMA DICOM standard

First entrance of the ICC profile into medical imaging in 2005 with the DICOM WK 11 **Supplement 100**:Color Softcopy Presentation State

ftp://medical.nema.org/medical/dicom/final/sup100_ft.pdf

QUBYX

ICC => Higher image quality - lower price

“The International Color Consortium was established for the purpose of creating, promoting and encouraging the standardization and evolution of an open, vendor-neutral, cross-platform color management system architecture.”

The ICC standard’s large success is due to the fact, that with it’s use, the color reproduction quality was increased and at the same time the price for hardware could be reduced.

While before only sophisticated high end devices could reproduce photos in the Photo and Pre-Press market correctly, today this is possible with cheap devices and the ICC color management system.

This new ICC standard for medical images offers the possibility for the same in the medical field.

Evolution of standard hardware

Thanks to the technical evolution the quality of hardware does increase.

-4k and 5k Displays with pixel pitch as small as 218 PPI (Pixel per Inch) on the iMac compared to 154 PPI on a 5MP mammography display
-LED backlights longer lifetime, better uniformity and more stable luminance
-larger sizes
-10 bit panels
-Large Gamut panels
-Standard graphic-boards supporting 10 bit and 12 bit LUT
-Display Port 1.3 with 16 bit and 8k resolution

CSDF calibration and ICC

The proposed CSDF calibration seems to increase the image quality for pseudo colors, but the proposed way uses cLUT Tables, which results in higher cost for the hardware. Instead of using a cLUT, that would only be available on certain hardware, the use of ICC profiles would make CSDF open, vendor-neutral and cross-platform.
We propose two ways of realisation:

1. **Use of ICC DeviceLink profiles**

2. **Specially calculated profile to achieve evenly spaced CIE-DE2000 differences for the particular display.**

Solution 1:
DeviceLink profile

DeviceLink profiles contain a pre-evaluated transform, which represents a link or connection between devices.
Often device links are used, to preserve the Black channel in the print of images and text. Device link profiles increase the quality of transformations.

DeviceLink profiles are N-component LUT-based ICC profiles.
Thus, for RGB-devices such profiles will contain 3D-LUT's
with RGB-to-RGB transformation.

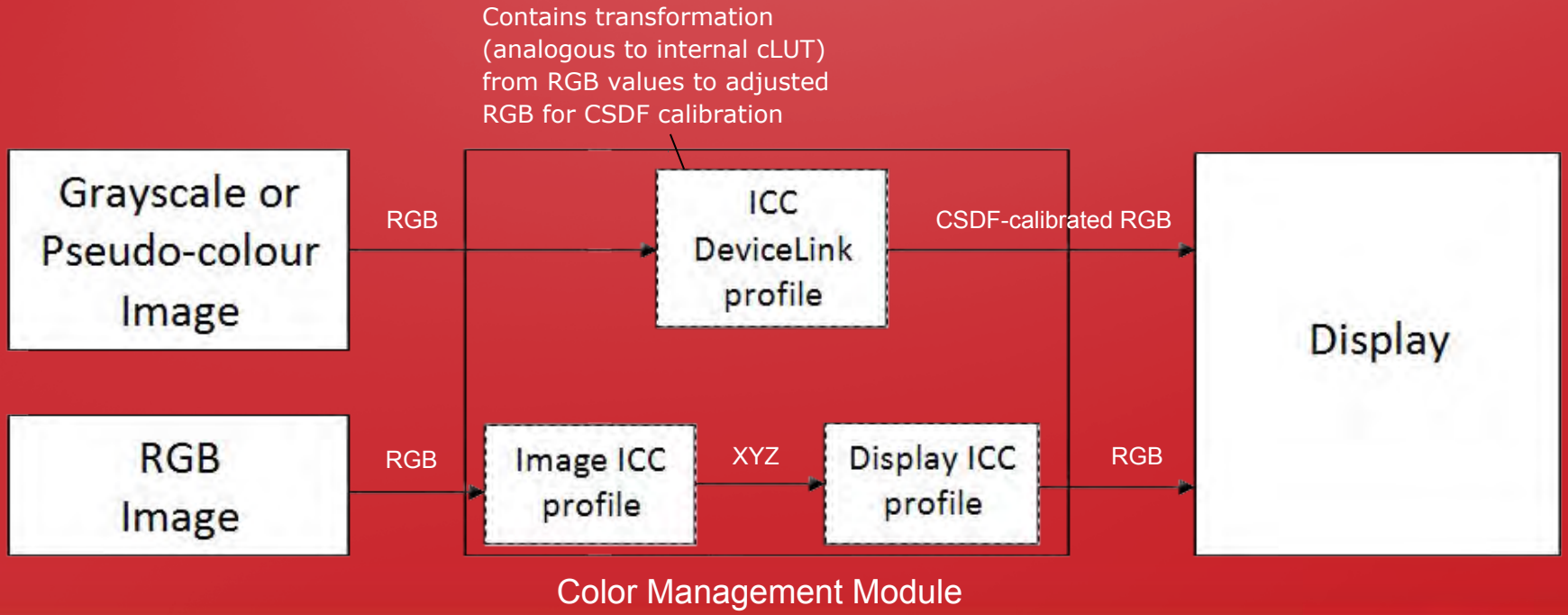
http://color.org/specification/ICC1v43_2010-12.pdf

In case of the CSDF calibration the DeviceLink profile will contain conversions analogous to the one offered to store in internal cLUTs to ensure evenly spaced CIE-DE2000 differences for colour primary and secondary scales. I.e. such a DeviceLink profile will map RGB values of the uncalibrated display to the new RGB of the to CSDF calibrated display.

To display Grayscale or Pseudo-colour images the DeviceLink profile will be applied before rendering the images on the displays.

In such case the display can be uncalibrated and the Colour Management System or application in which the images will be viewed shall be able to apply the DeviceLink profile before displaying Grayscale or Pseudo-colour image.

Display of medical images



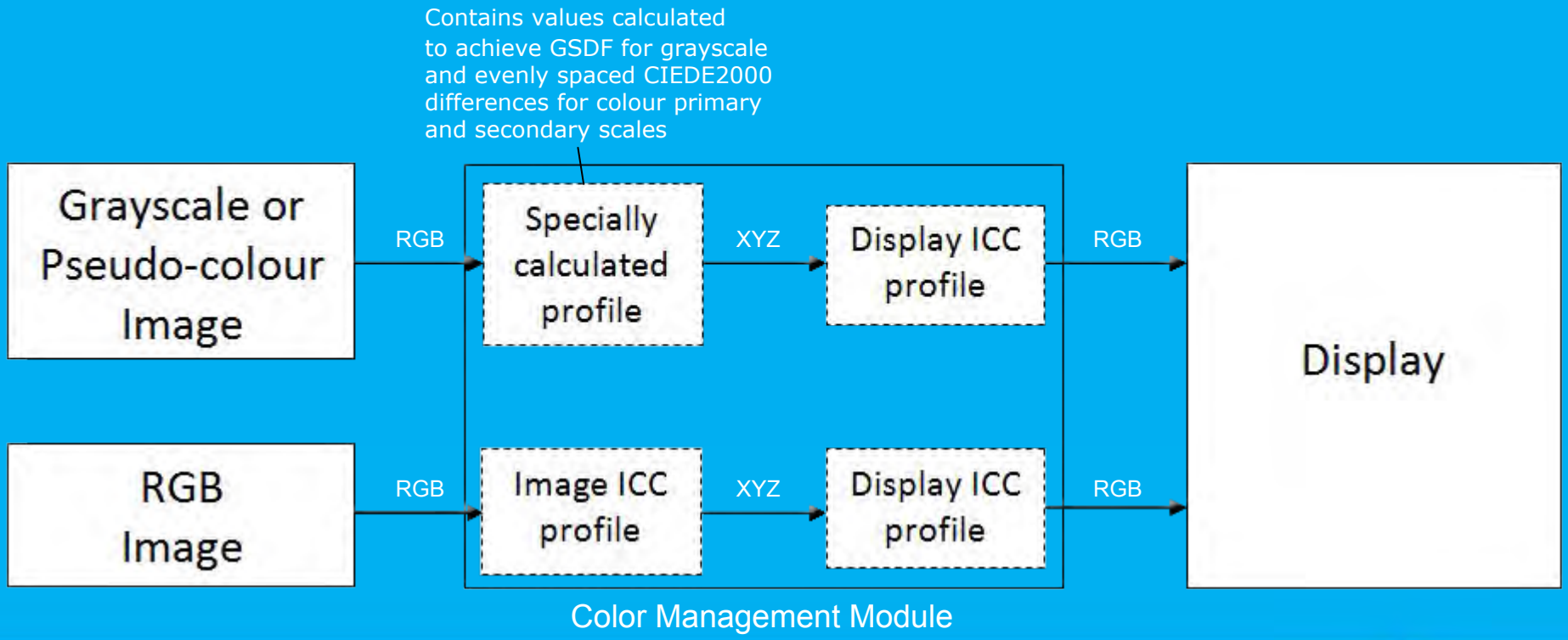
Solution 2:
The use of specially calculated profile

This solution offers calculation of special N-component LUT-based ICC profile for the particular display to obtain the proposed CSDF evenly spaced colors.

Such a profile can be:

- **applied to every grayscale or pseudo-colour image which will be displayed**
- **used as a working space profile (like standard AdobeRGB, sRGB profiles etc. are used in Photoshop)**

Display of medical images



Advantages of solution 1 - Device Link Profiles

-High quality color transformation thanks to the internal 3D LUTs and 16-bit precision
-less errors due to absence of RGB-XYZ and XYZ-RGB transformations through profiles (compared to Solution 2)
-independence of display profile quality
-Change between Color and GSDF on the fly
-Display in native or CIE L* status with lowest deficit in color gamut and dynamic range
-can be several DeviceLink profiles created for CSDF-calibration from different display states

Colors and Pseudo colors / dRGB

Mr. Craig Revie shows in his document from July 2015, that most medical color images use pseudo colors and discusses the calibration to CSDF seems to be of benefit.
While there are more displays in numbers showing Pseudo colors then real colors, there is a by far larger concern about the reproduction quality in real color images.
For color images the use of the Gamma power function is still widespread. The Gamma power function was invented for analog display systems. Today the CIE L* function would be more appropriate to display color shades equidistant.
The Lmax of 350cd/m2 in dRGB is not appropriated for many modalities. Would Endoscopy manufacturers not like to follow REC 709 and Rec 2020 ?

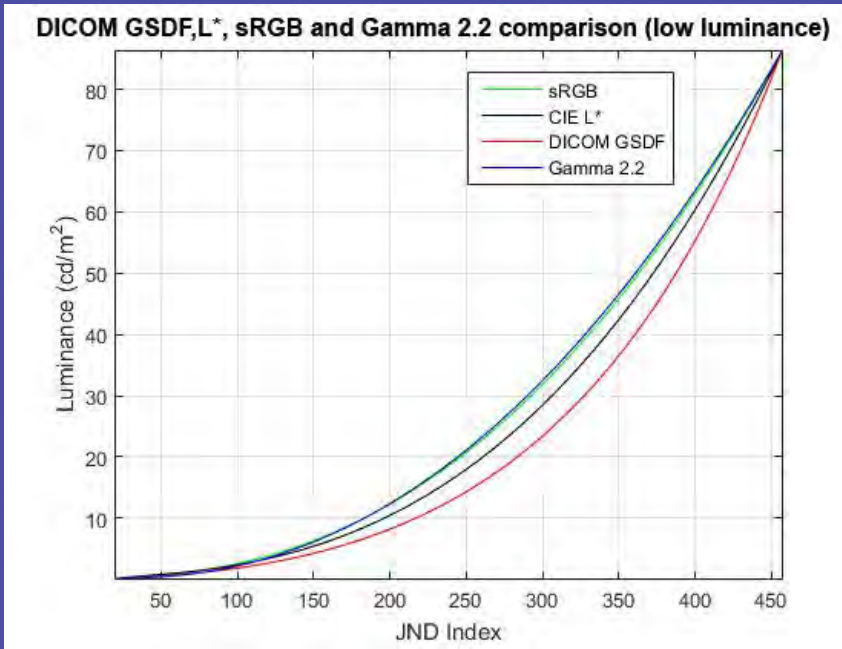
CIE L* calibration and ICC

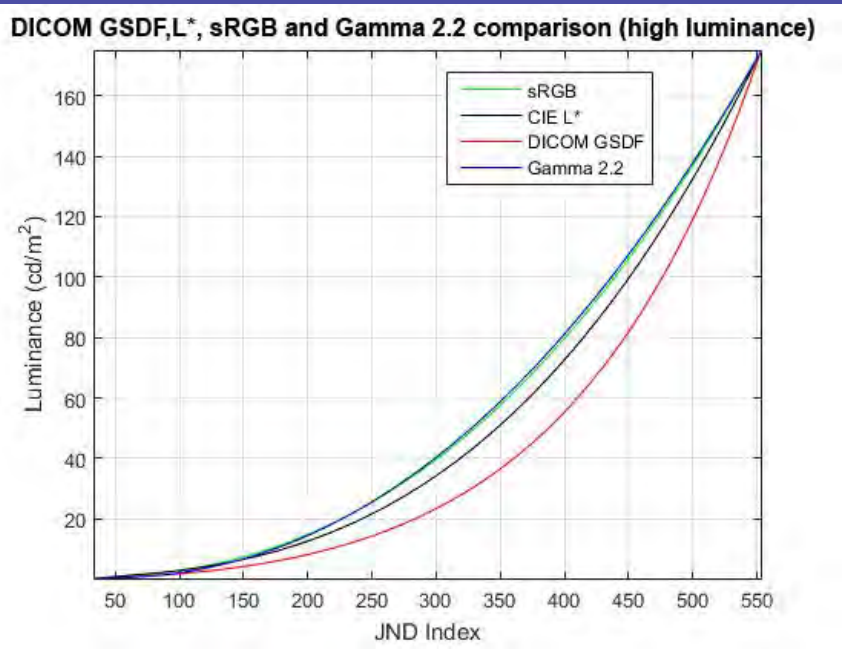
The CIE L* calibration has the advantage to display colors equidistant for the human observer. So it is perfect for color images. The L* curve approximates the human ability to perceive brightness differences. The function is perceptually linear to make more levels available for rendering blacks (dark area), thereby improving shadow definition.

$$Y_{L^*} = \begin{cases} Y_{min} + (Y_{max} - Y_{min}) \dfrac{2700 \cdot DDL_j}{24389 \cdot DDL_{max}}, & if \quad DDL_j \leq DDL_{max} \cdot \dfrac{216}{2700}, \\ Y_{min} + (Y_{max} - Y_{min}) \left(\dfrac{100 \dfrac{DDL_j}{DDL_{max}} + 16}{116} \right)^3, & if \quad DDL_j > DDL_{max} \cdot \dfrac{216}{2700}. \end{cases}$$

The ICC profile can be a v2 or v4 profile applied in the viewing application. But also just a LUT will make it.

DICOM GSDF, L*, sRGB and Gamma 2.2 comparison





QUBYX

sRGB and L* calibration comparison

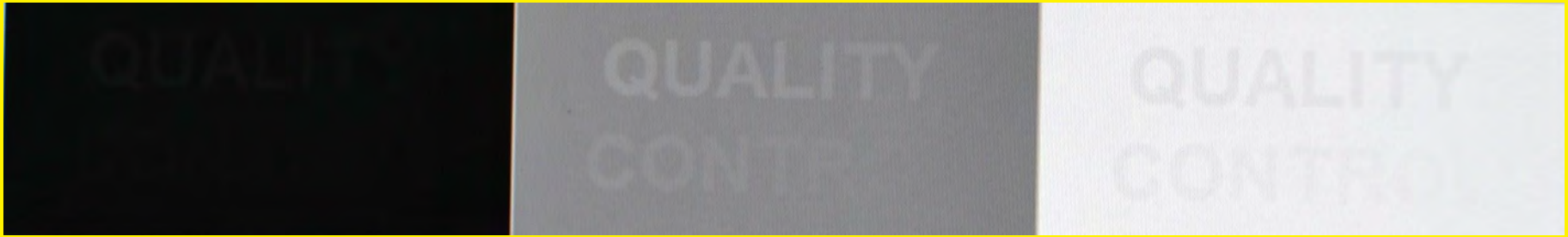
sRGB calibration

L* calibration

Images taken with a camera of the same display calibrated to CIE L* and sRGB

QUBYX

sRGB and L* calibration comparison



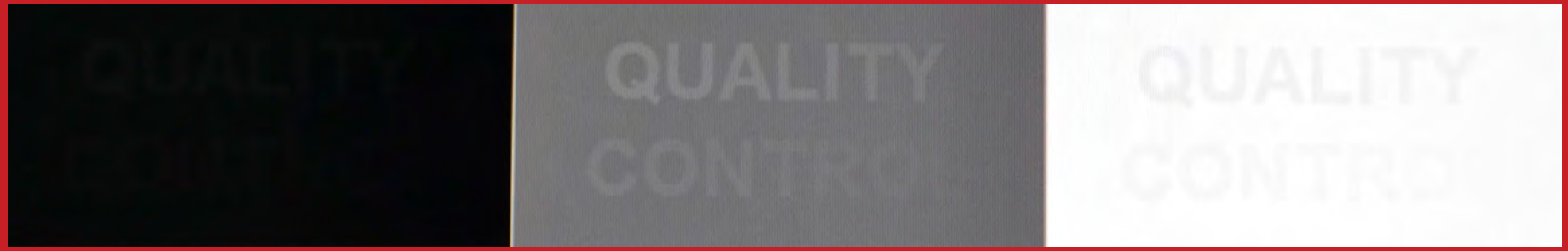
sRGB calibration

L* calibration

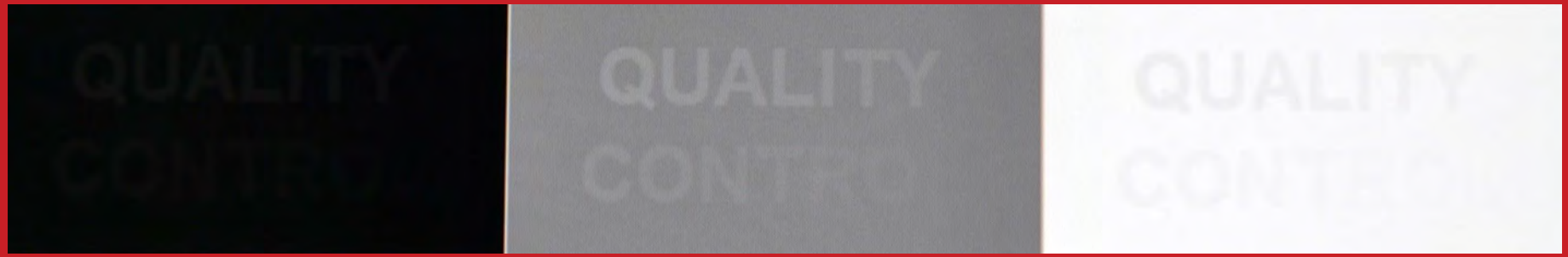
Images taken with a camera of the same display calibrated to CIE L* and sRGB

QUBYX

DICOM GSDF and L* calibration comparison



DICOM calibration



L* calibration

Images taken with a camera of the same display calibrated to CIE L* and DICOM GSDF

QUBYX

Estimation of the calibration error associated with the use of a film calibration target

W Craig Revie

October 2015

FFEI Limited

Digital microscope film calibration target

HutchColor HCT Ektachrome™ 35 mm

It has been observed in previous discussions in the ICC Medical Imaging Working Group that calibrating a digital microscope using a film target will introduce errors. These errors arise because the spectral characteristics of the dyes used in photographic film are significantly different from the stains used in pathology.

The aim of this project is to estimate the likely size of the error introduced compared to calibration using a calibration method that takes into account the spectral characteristics of the stains.

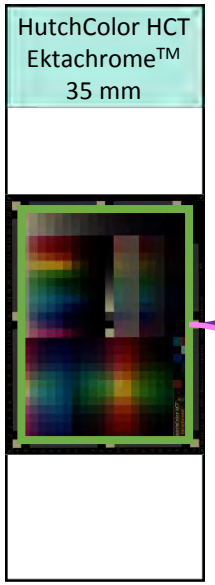
The magnitude of the errors introduced by a mismatch between the spectral characteristics of the calibration patches used to calibrate the system is difficult to estimate precisely as they depend on a number of factors including the light source and sensor sensitivities.

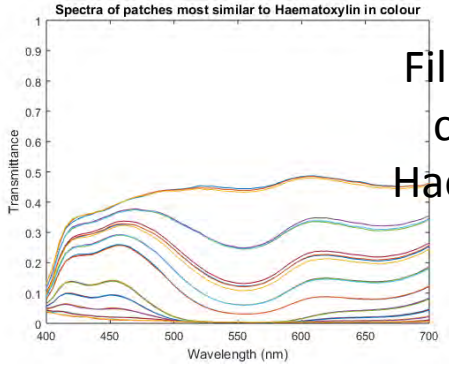
This presentation uses a representative source and typical sensor sensitivities to estimate the likely size of errors – in many cases the errors will be substantially larger than those estimated here.

Measurements of film and stained tissue

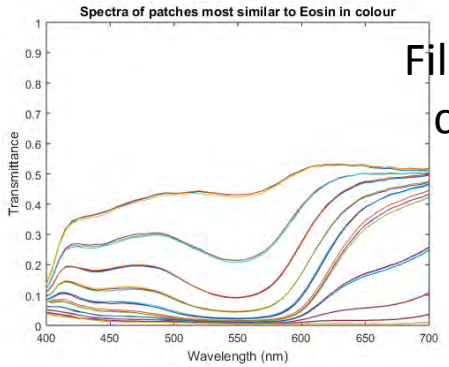
Measurements of calibration slide

HutchColor HCT Ektachrome™ 35 mm





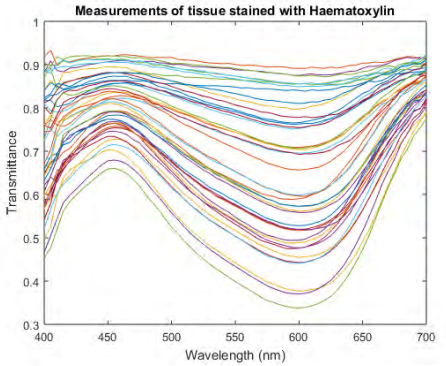
Film patches closest to Haematoxylin



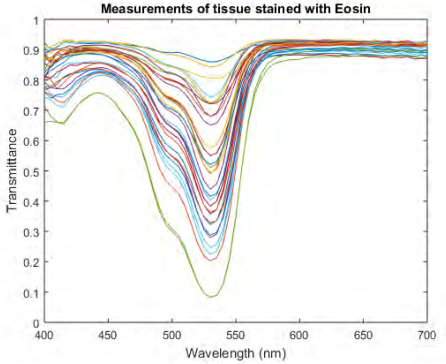
Film patches closest to Eosin

Measurements of H&E stained tissue

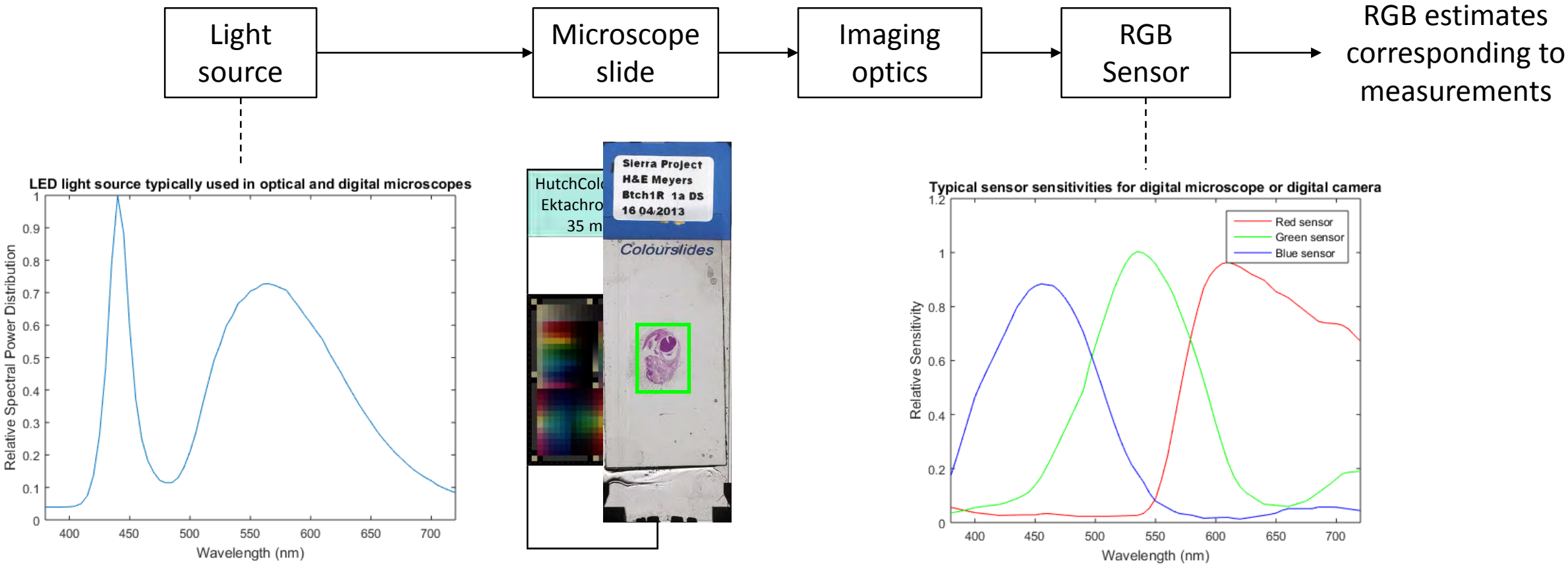
Measurement of tissue stained with Haematoxylin



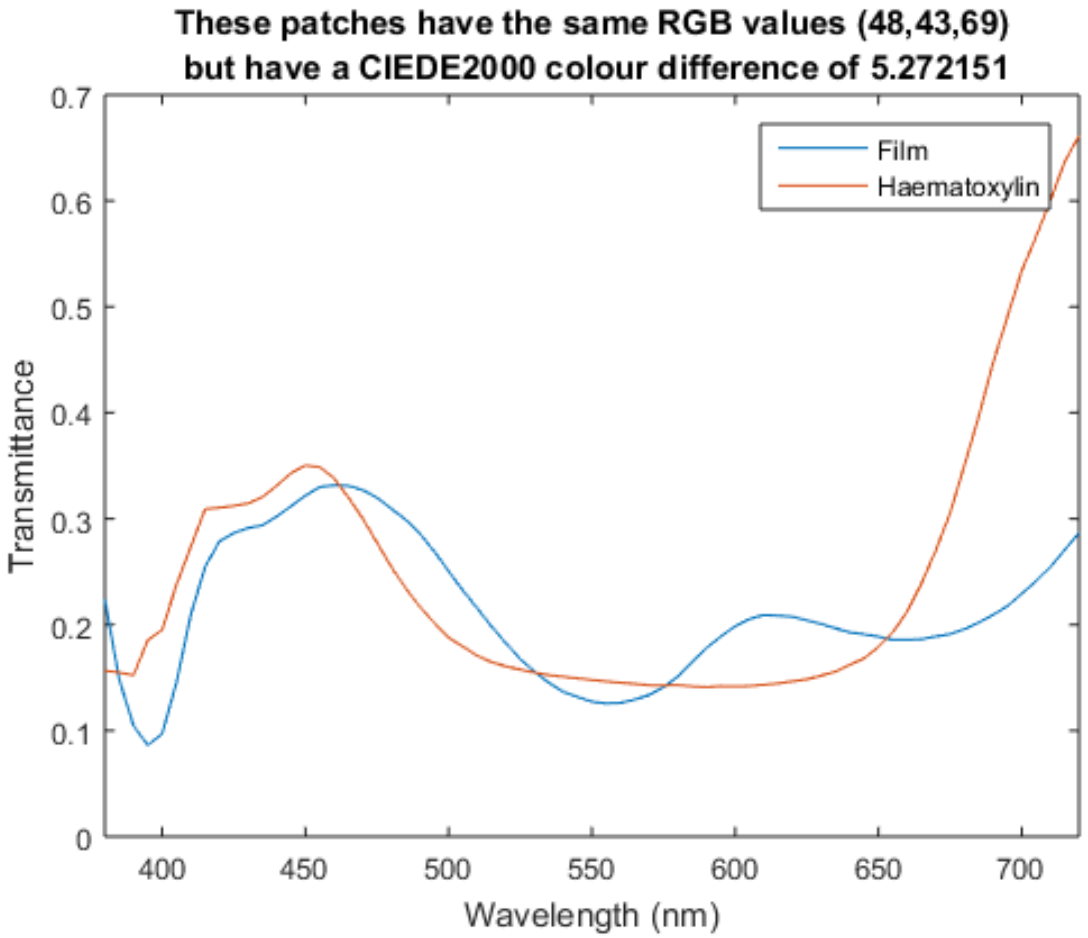
Measurement of tissue stained with Eosin



RGB scanner model



Haematoxylin

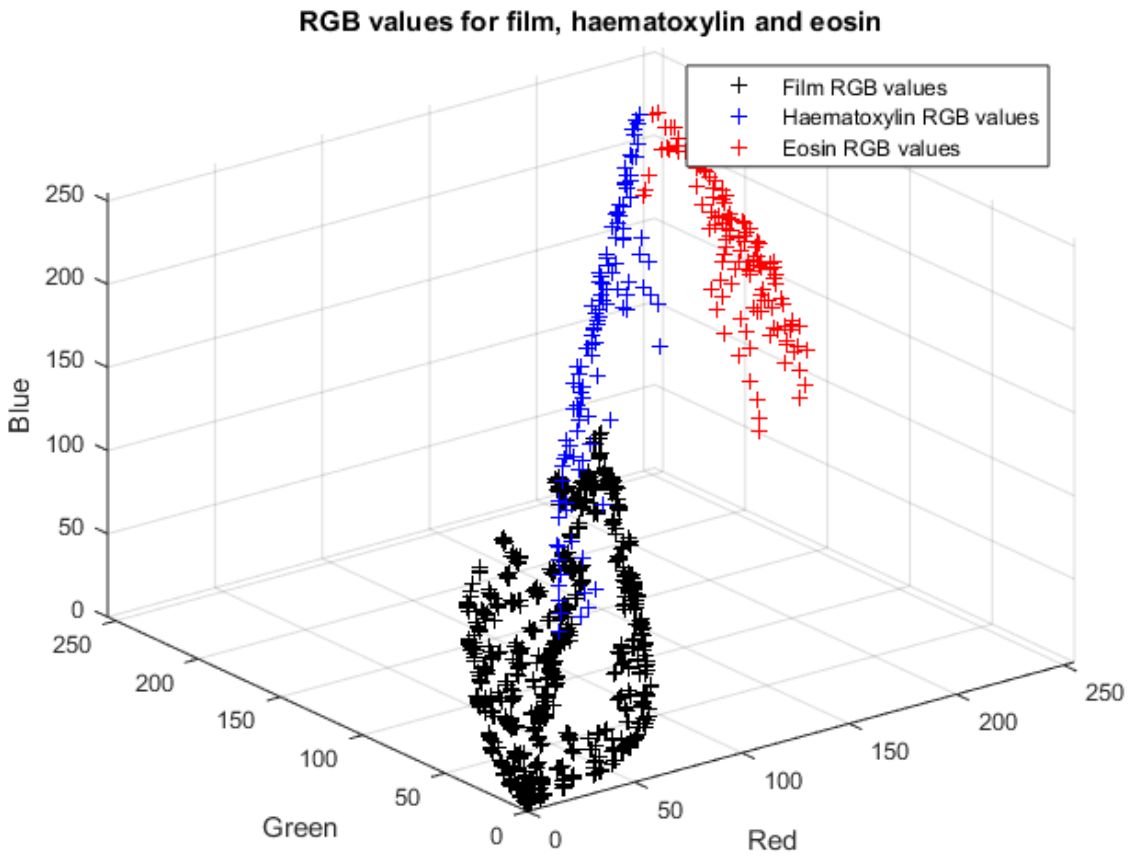


This figure shows the spectral transmittance for a measurement from the film target (blue) and a measurement of Haematoxylin-stained tissue (red)

These patches have the same RGB values (48,43,69) but differ in colour by more than 5 CIEDE2000

This error is a systematic error and cannot be corrected by the calibration software and is larger than the total colour errors we aim to achieve for a calibrated digital microscope system

Different RGB gamuts



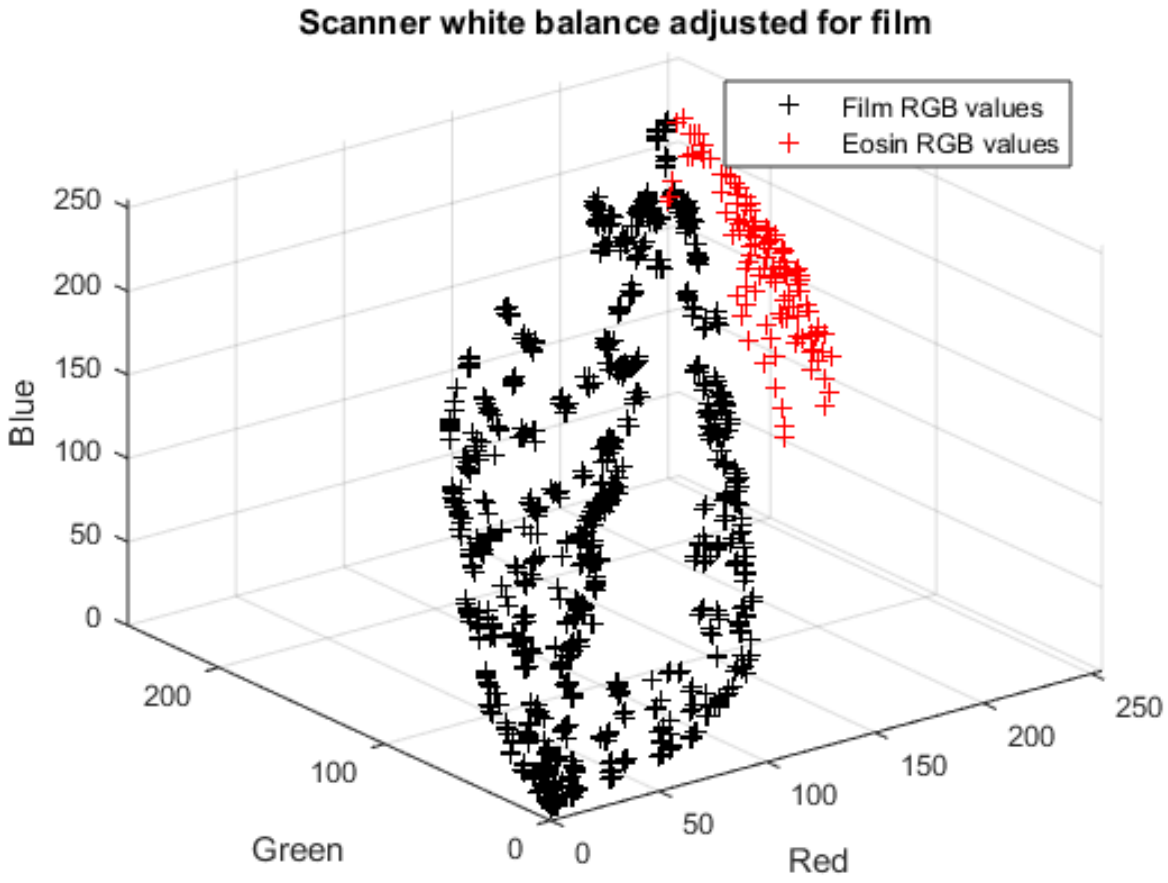
This figure shows measurements from film (black) Haematoxylin-stained tissue (blue) and Eosin-stained tissue (red)

Film is more dense than tissue and this means that most of the RGB values that arise when scanning stained tissue are not seen by the scanner during calibration

This means that the colour corresponding to RGB values for Haematoxylin and Eosin cannot be estimated with any degree of precision

It is not easily possible to estimate the size of these errors precisely but typically errors in estimating colours outside the gamut of the training set (the calibration target) are likely to be greater than 10 CIEDE2000

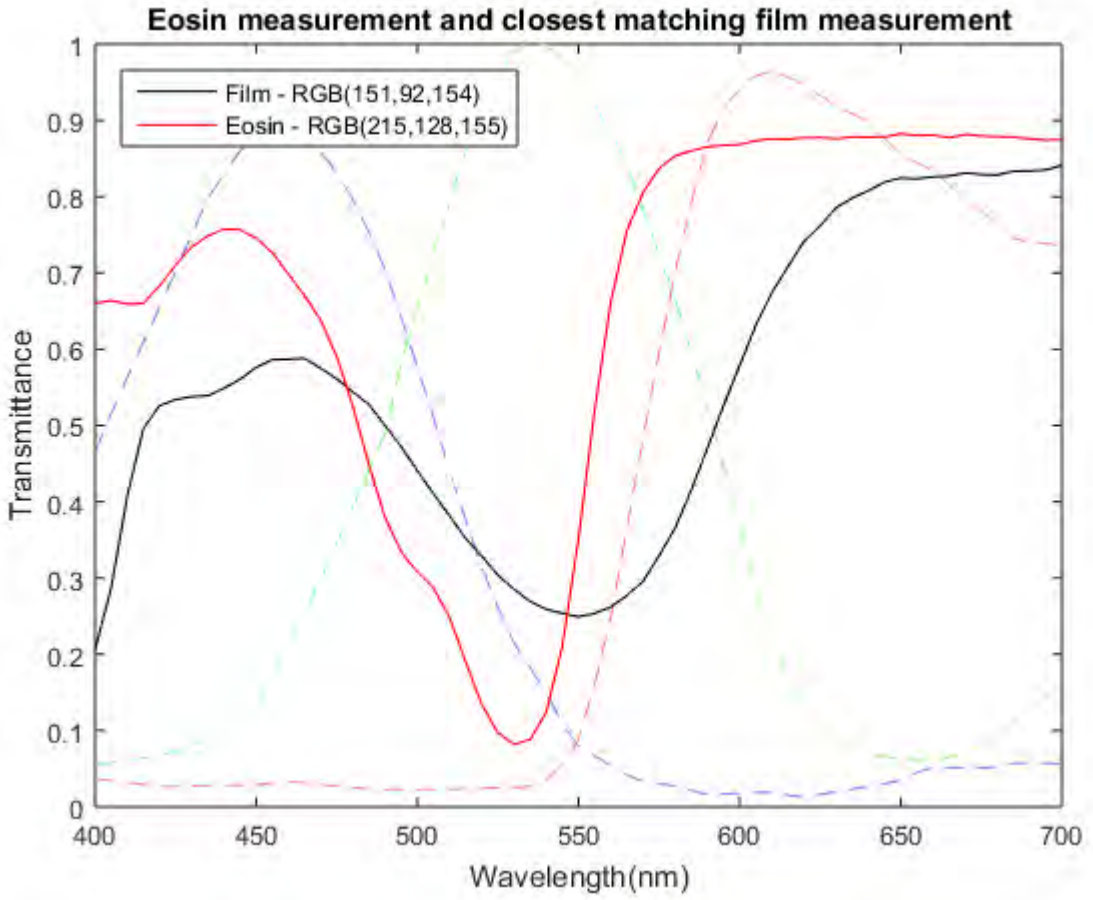
Eosin



Even if the effect of the film base is removed, for example by white balancing, Eosin RGB values are significantly outside the film gamut

Using a different white balance for calibration and scanning of tissue samples introduces additional errors

Eosin vs film



By comparing the shape of the spectrum for an Eosin patch and the closest matching film patch with the sensor sensitivities it can be seen that they are very different shapes

This difference in shape when compared with the shape of the sensor sensitivities explains the reason for the very different colour gamuts

Trying to estimate the colour of eosin from the RGB values of the scan of the calibration target will include a large uncertainty

Whole Slide Imaging Sierra status summary

W Craig Revie

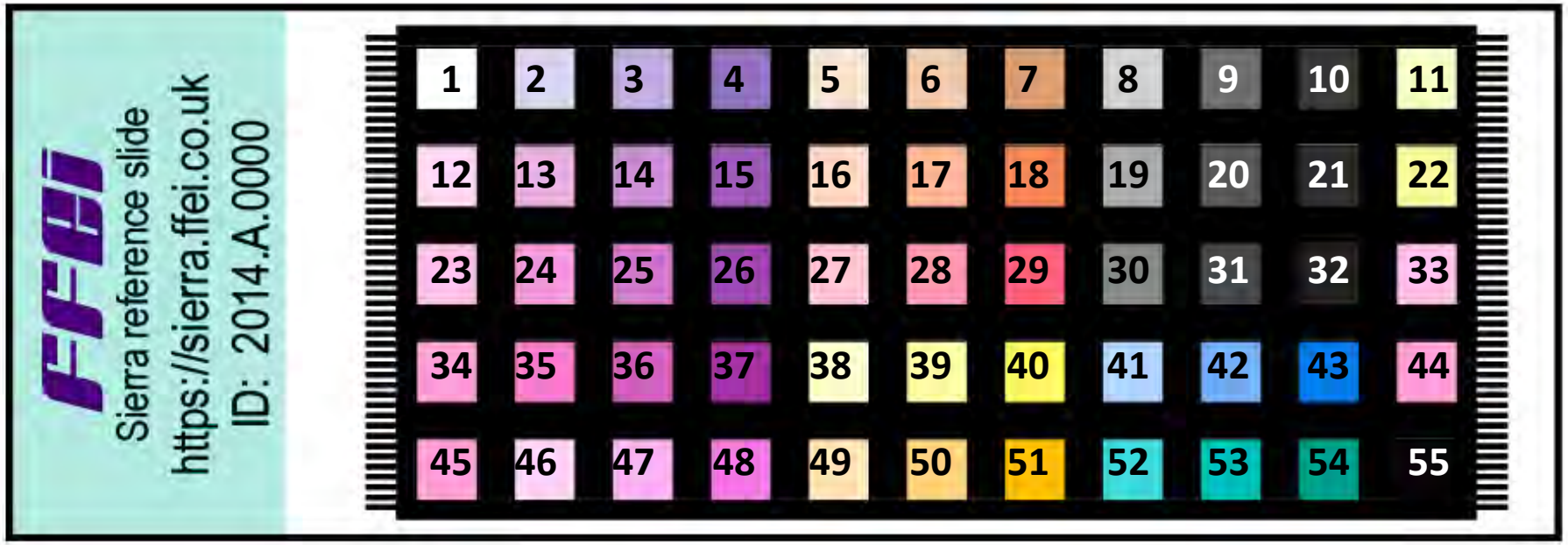
October 2015

Sierra status

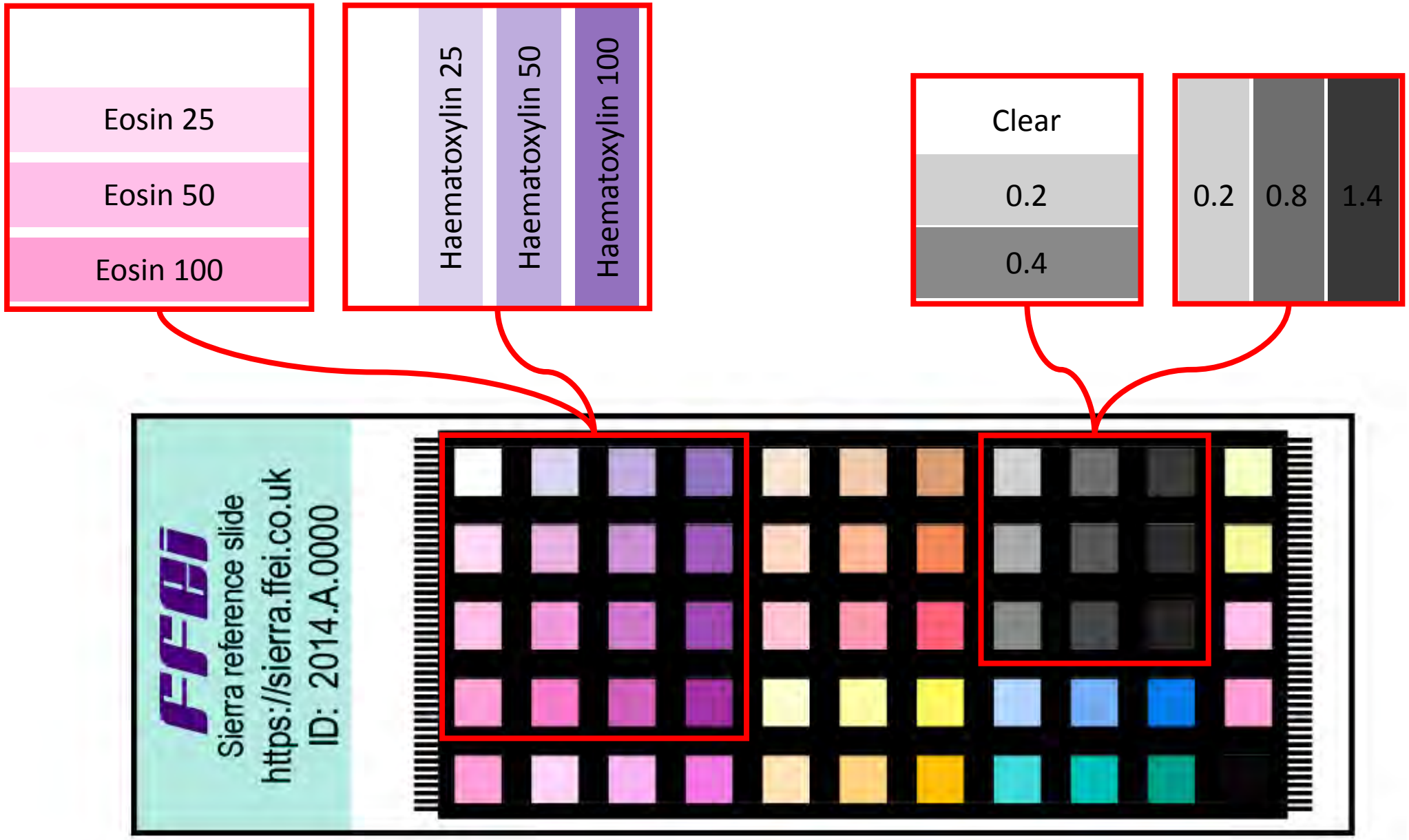
- Calibration assessment slide evaluated on a number of different ‘calibrated’ systems showed significant differences
- An extended calibration slide has been developed and is being evaluated on a number of systems
- This slide includes a number of different stains used in pathology

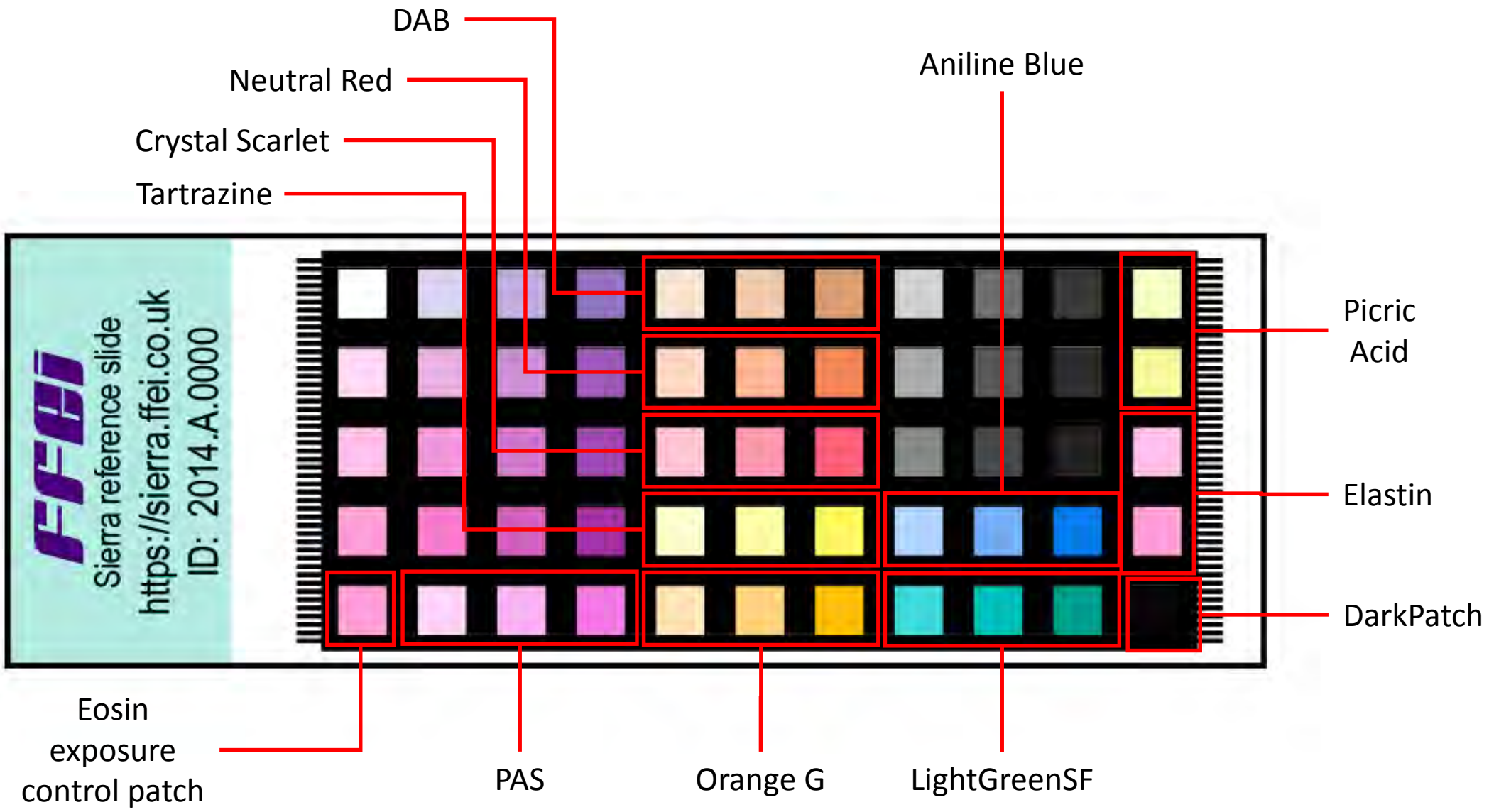
- **Method:** evaluators scan slide and make image available to FFEI, we hold measurement data for each patch of the slide and will build an ICC Profile that should be included in subsequent scanned images

Sierra Calibration Slide v2



1	H0E0	2	H25E0	3	H50E0	4	H100E0	5	DAB_25	6	DAB_50	7	DAB	8	N1	9	N4	10	N7	11	PicricAcid_50
12	H0E25	13	H25E25	14	H50E25	15	H100E25	16	NeutralRed_25	17	NeutralRed_50	18	NeutralRed	19	N2	20	N5	21	N8	22	PicricAcid
23	H0E50	24	H25E50	25	H50E50	26	H100E50	27	CrystalScarlet_25	28	CrystalScarlet_50	29	CrystalScarlet	30	N3	31	N6	32	N9	33	Elastin _50
34	H0E100	35	H25E100	36	H50E100	37	H100E100	38	Tartrazine_25	39	Tartrazine_50	40	Tartrazine	41	AnilineBlue_25	42	AnilineBlue_50	43	AnilineBlue	44	Elastin
45	EosinControl	46	PAS_25	47	PAS_50	48	PAS	49	OrangeG_25	50	OrangeG_50	51	OrangeG	52	LightGreenSF_25	53	LightGreenSF_50	54	LightGreenSF	55	DarkPatch


Eosin 25
Eosin 50
Eosin 100
Haematoxylin 25
Haematoxylin 50
Haematoxylin 100
Clear
0.2
0.4
0.2
0.8
1.4
FFEI
Sierra reference slide
https://sierra.ffei.co.uk
ID: 2014.A.0000


DAB
Neutral Red
Crystal Scarlet
Tartrazine
Aniline Blue
Picric Acid
Elastin
DarkPatch
Eosin exposure control patch
PAS
Orange G
LightGreenSF
FFEI
Sierra reference slide
https://sierra.ffei.co.uk
ID: 2014.A.0000

Slide manufacture

- FFEI can manufacture and measure these slides in small numbers
- We would like to find a more reliable manufacturing method and are looking for suitable partner companies
- In the meantime a number of organisations are using the slide to calibrate their systems and will provide feedback

Medical Photography

Draft circulated in April 2015

- Based on good practice in professional photography
- Based on commercially available equipment
- DSC capture, not other modalities
- ICC only realistic option for open-source calibration

Progress Report: Color Consistency Analysis in Fundus Photography

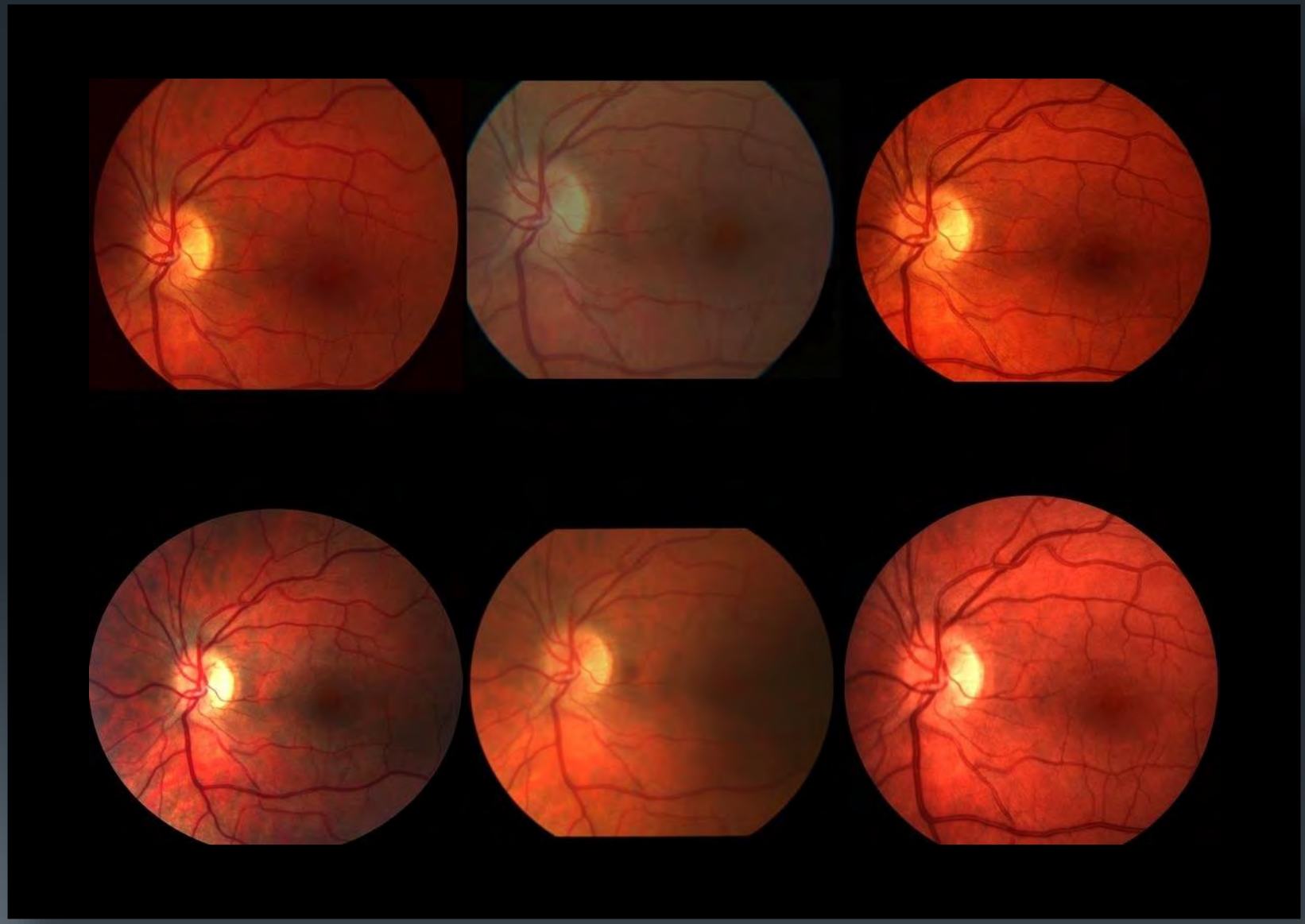
Christye P. Sisson, CRA, MS

Associate Professor

Ronald and Mabel Francis Endowed Chair, Program Chair: Photographic Sciences

School of Photographic Arts and Sciences

Image Variables

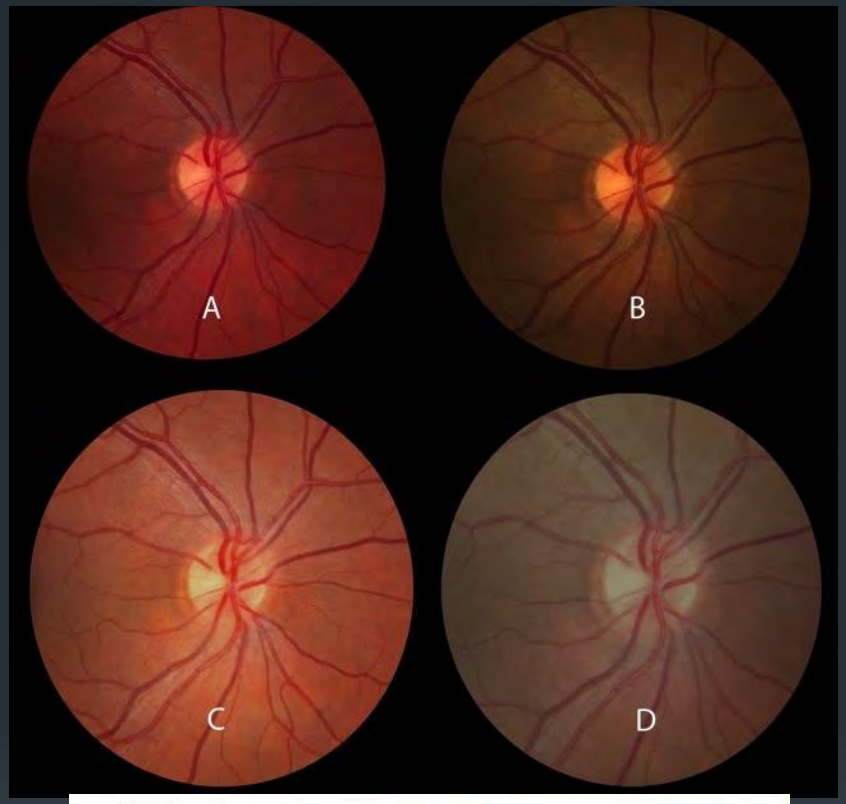


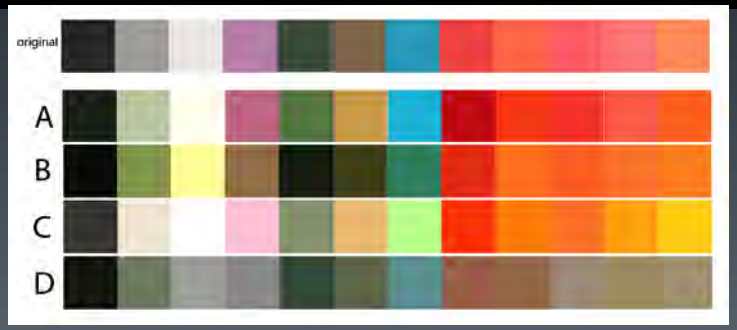
Imaging Procedure

- Iris dilated pharmaceutically
- Once dilated, patient aligned in fundus camera headrest
- Photographer adjusts working distance for optimal illumination, focus
- Photograph taken using flash

Image courtesy of National Eye Institute: http://www.stylewiz.com/mnr/nei/photo-gallery.php

Phase I: Captured vs. Processed





Before

After

Phase I: Conclusions

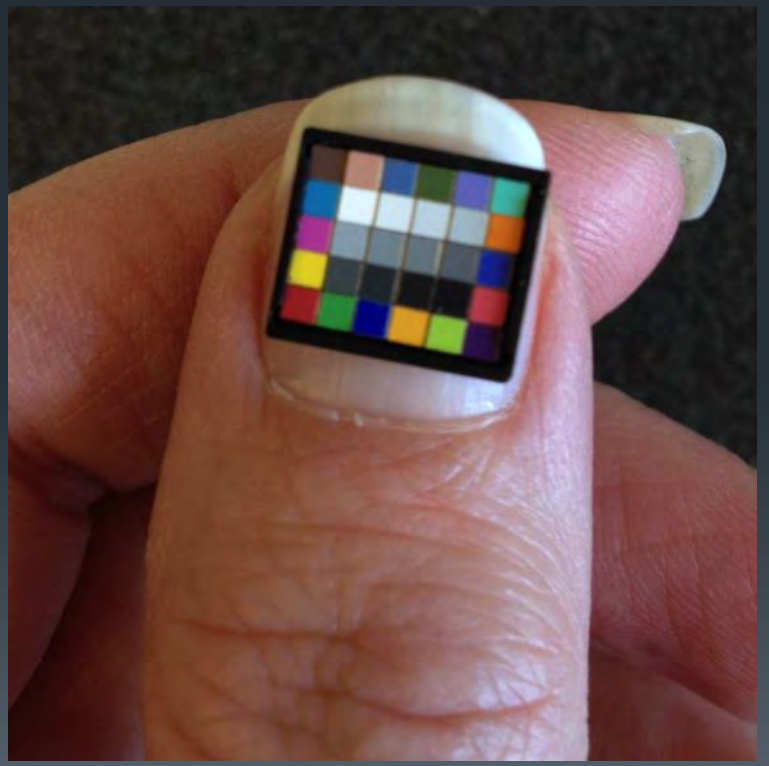
- It is potentially possible to profile a fundus camera, at least individually
  - Applying to RAW image in system would be ideal
- *What we as ophthalmic imagers and practitioners believe to be “correct” retinal color is not correct at all*
- A standard approach to color calibration is needed to mitigate input variables

Color Model Eye Project (MIWG) : Phase II

- Determine minimum color patch size
- Refine testing materials
  - Use of a standard color checker
  - Use of a aspherical model eye
- Determine imaging protocol

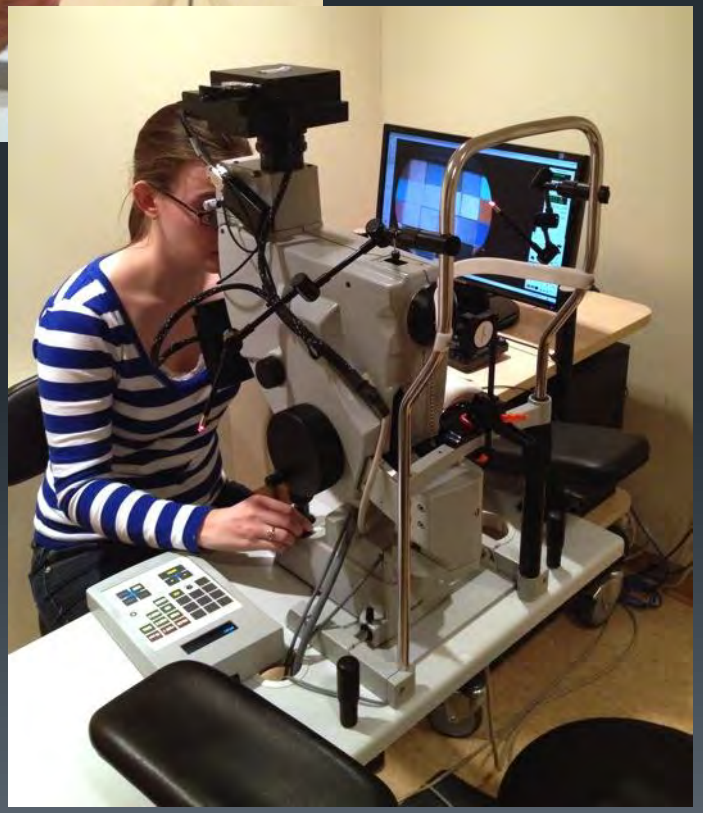
A Better Target (A really, really, really tiny Color Checker)

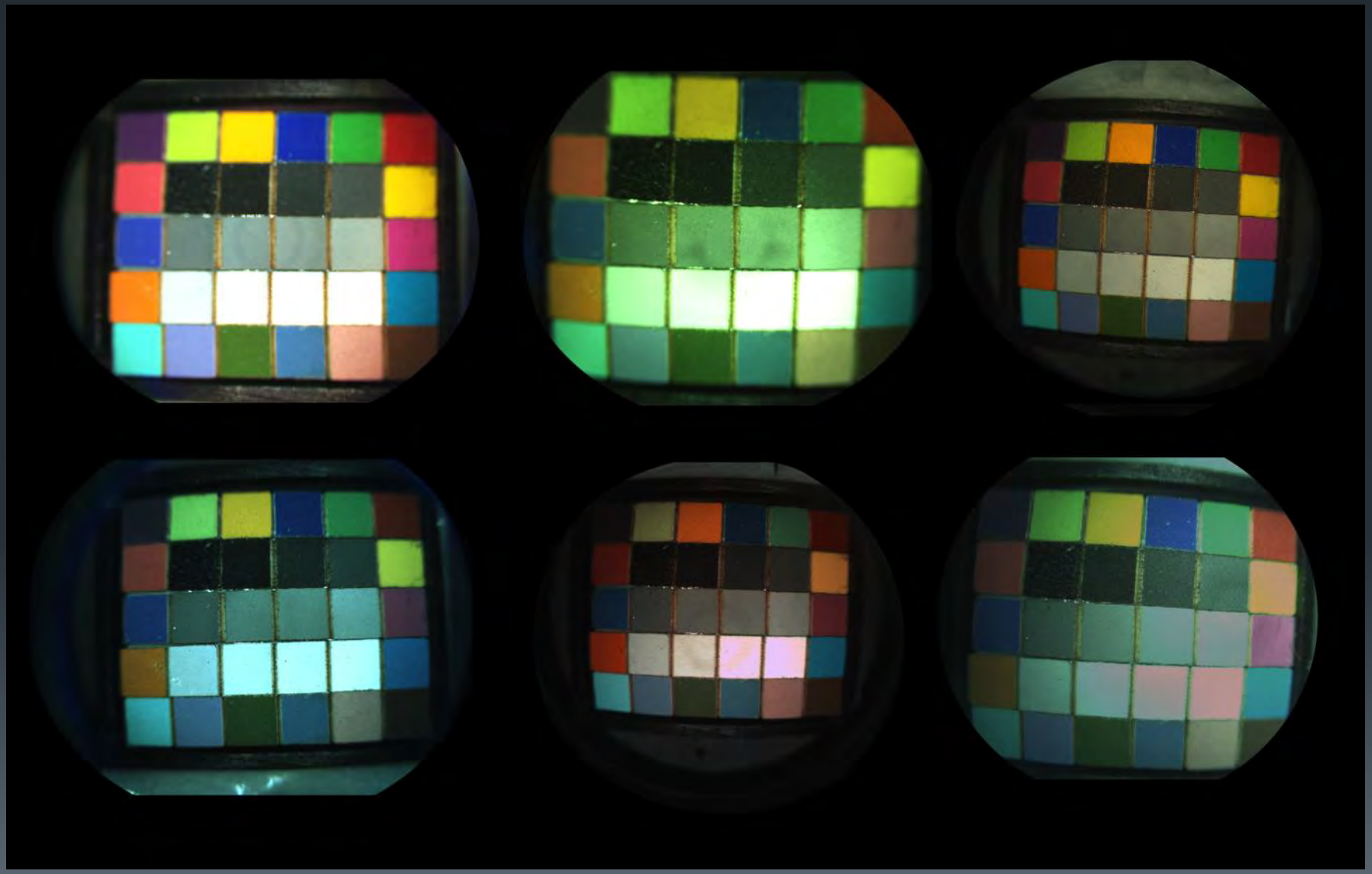
- Identical color patches to GretagMacbeth™ ColorChecker®, 1/12th original size
- Pigmented, painted samples
- Flat field



Protocol

- Inserted test target into model eye
- Chose “middle” angle of view
- Established proper alignment/working distance/focus
- Reduced viewing illumination
- Captured at “normal” exposure, +/-





Phase III…

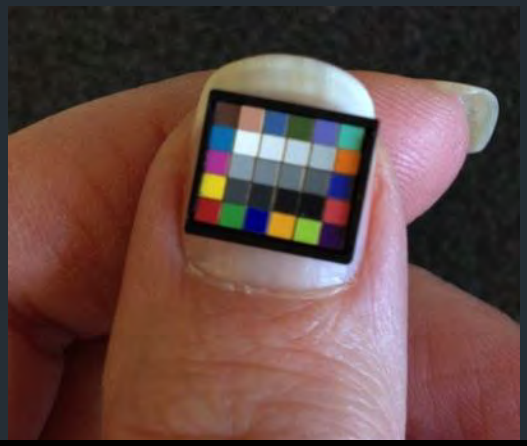
- Modify color patches, model eye if needed
- Extended camera testing at multiple sites
- Software implementation strategies
- Final feasibility report
  - Manufacturer vs. User implementation

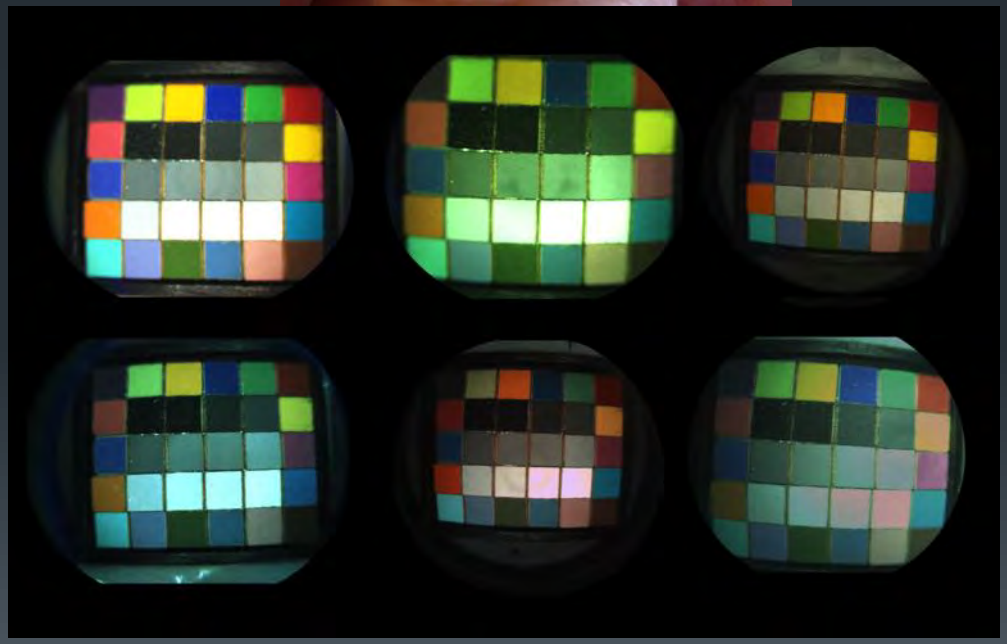
Modifying colors

161 47 18	199 73 26	122 86 69	180 99 73	191 86 58	228 162 137	208 81 55	249 123 85
251 181 143	193 71 27	119 41 28	125 82 65	127 89 71	170 119 106	144 56 32	229 105 66
181 71 21	217 131 58	175 67 29	223 132 58	169 59 28	228 138 71	116 35 24	218 120 93
131 52 5	189 71 16	143 58 24	200 107 46	178 77 31	224 152 78	61 31 23	114 75 65
187 119 99	226 169 142	180 58 23	213 100 43	180 45 1	254 168 87	174 85 44	198 107 55
111 68 47	223 146 116	182 91 38	215 125 57	135 40 3	214 88 25	128 61 28	240 198 116

Modifying target

- Phase II target is flat
- Fundus camera designed for curved field (inside of the globe)
- Working with Image Science Associates to produce a curved target to match curvature of field
  - Should minimize aberrations present in Phase II





Modifying model eye

- Original model eye was plastic, inconsistent with optical properties of a human eye
- Phase II model eye included aspheric lens of increased optical power, but proved too great a magnification to include standard field of view (and target) for some cameras
- Phase III model eye
  - Lower power optics

Thanks to:

Color Model Eye Group Members

- Bill Fischer *Flaum Eye Institute, University of Rochester Medical Center*
- Jim Strong *Penn State Hershey Eye Center*
- Tim Bennett *Penn State Hershey Eye Center*
- Mark Fairchild *Munsell Color Science Laboratory, Rochester Institute of Technology*
- Susan Farnand *Munsell Color Science Laboratory, Rochester Institute of Technology*
- Matt Carnavale *Sonomed/Escalon*
- Kevin Langton *Carl Zeiss Meditec*
- Rich Amador *Canon*
- Dennis Thayer

cpspph@rit.edu

Petri dish imaging

Project leader

Jérémie Pescatore (bioMérieux)

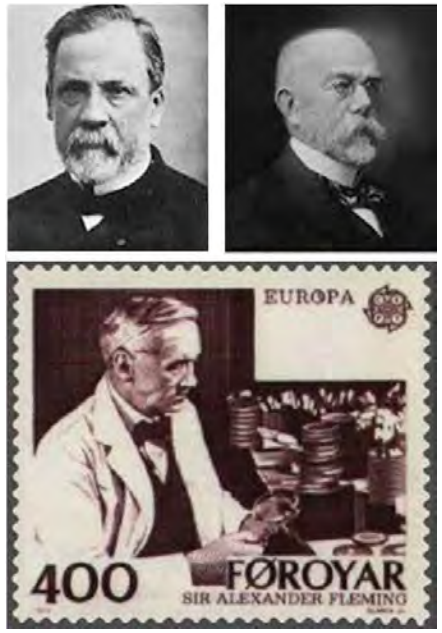
Applications

Framework for colour in petri dish imaging

Main focus

Development of suitable calibration materials

Pasteur revisited: no future for Petri dish?



http://www.microbialart.com/

Are the good old days of the organism growth observation on agar plate over?

Is the Petri Art the only foreseeable future for the plates ?

Petri dish has a great future thanks to Microbiology Laboratory Automation

- Wave of lab automation
  - productivity, limited resources, lower reimbursement, less qualified staff, higher quality required...
- No breakthrough technology : culture-based microbiology will always be a fundamental part of diagnostics
- Path forward is plate imaging associated to automated incubation step

WASPLAB, Copan

(bioMérieux strategic partner)

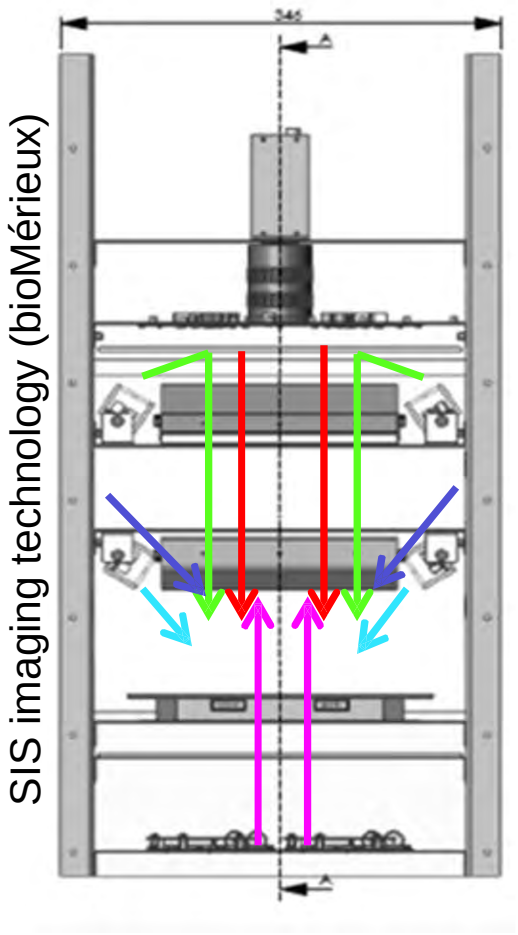
WCA, BD Kiestra

Changing Clinical Microbiology Practices

- Switching from a visual reading to a virtual reading introduces some limitations
  - no smell
  - no 3D vision
  - no option to move the plate in front of a light source
- The challenge is to convert the user by providing the same level of information

The imaging system has to deliver images of very high quality

How to provide high quality images?



IIIlumination #1 (TopVertical)

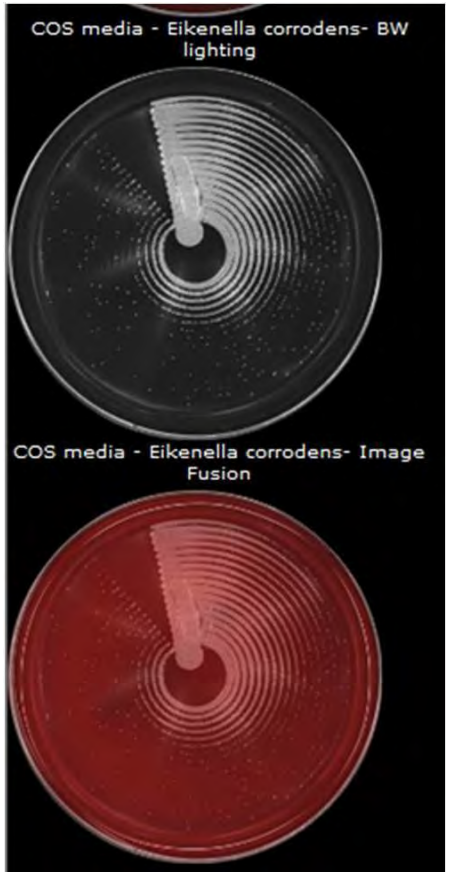
Illumination #2 (TopAnnular)

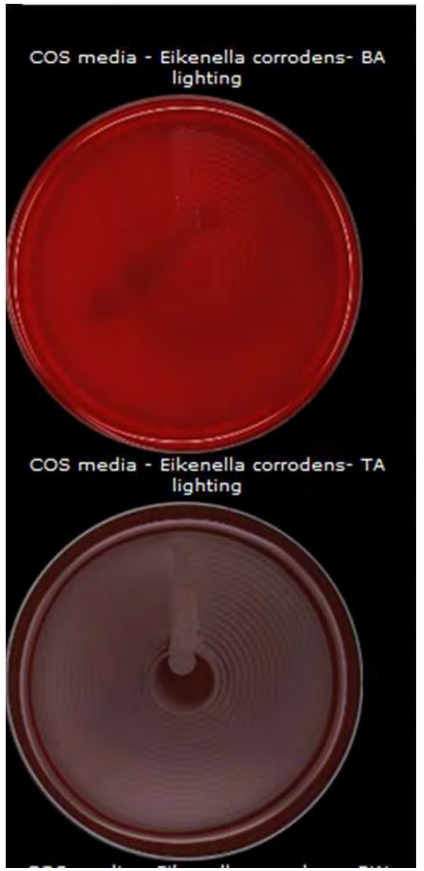
Illumination #3 (BottomAnnular)

Illumination #5 (UV)

Backgrounds (w/o, white, black)

Illumination #4 (Backlight)





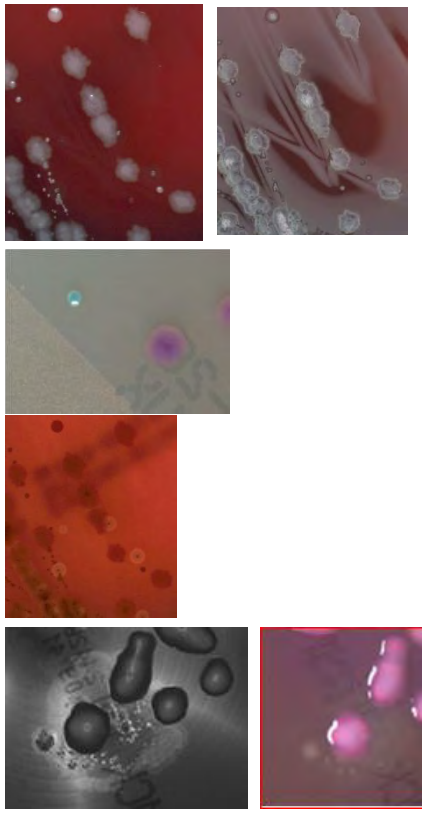
Providing different lighting conditions and exposure to maximize information

User Needs: requirements and verification

The virtual reading shall allow to :

1. Detect growing colonies of a minimum size
2. Reliably distinguish different type of colonies (ie ***morphotype***) on the same plate
3. Distinguish colonies by **their color** on chromogenic media
4. Detect **hemolysis** (alpha & beta) at the surrounding of the colonies
5. Detect **swarming** at the surrounding of the colonies

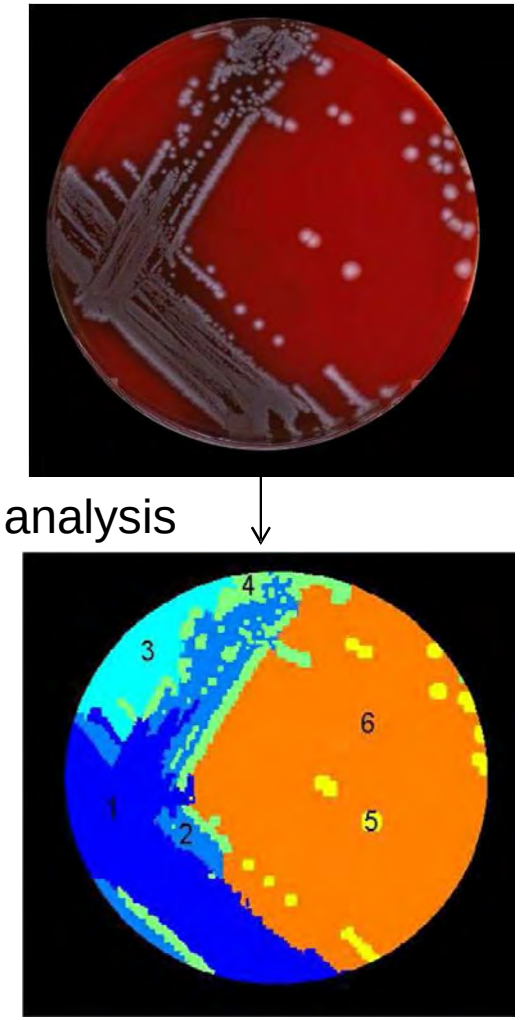
Virtual reading **shall be at least equivalent** to manual reading



Is the quality of images sufficient for decision making?

Added value of petri plate imaging is in intelligent image analysis and decision algorithms which can extract more information from the picture:

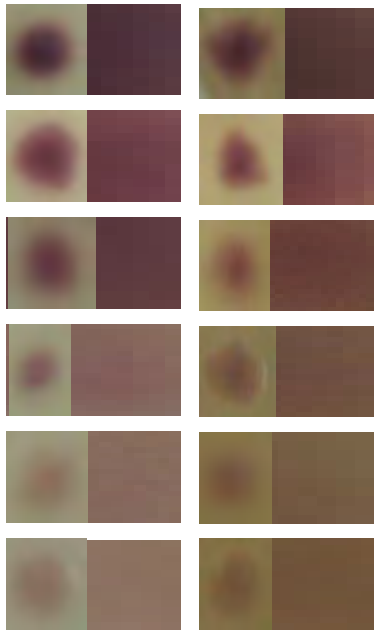
- growth / no growth
- identification and colony picking recommendation



Scalable algorithms for automated decision making

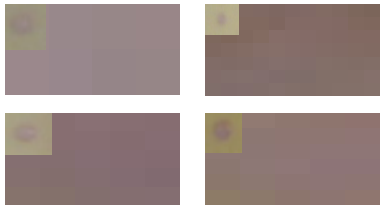
Colours Reading Scale Complexity

1: Species A
Pale pink to burgundy

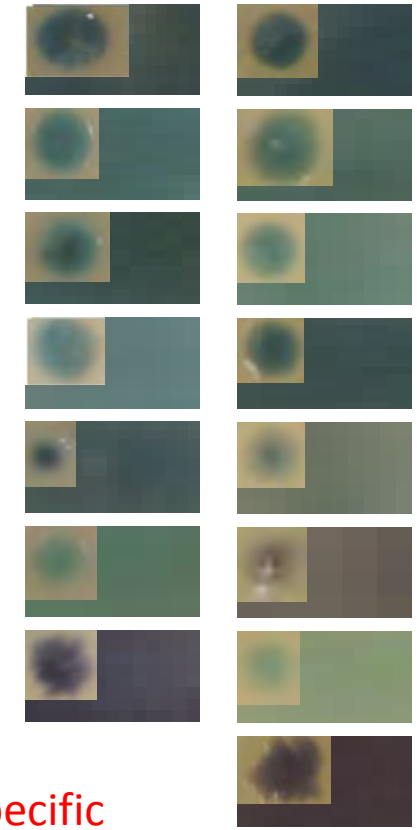


2: Species B
Small turquoise colonies

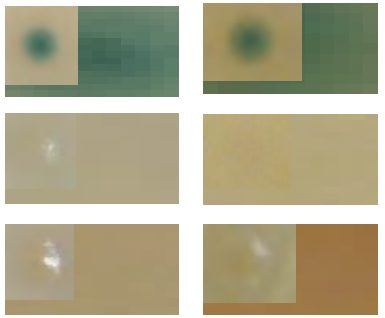
5: Species E
Matte pink and small colonies



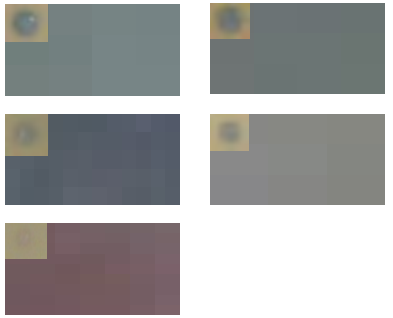
3: Species C
Blue-green to Blue-violet



4: Species D
Beige, green or brown

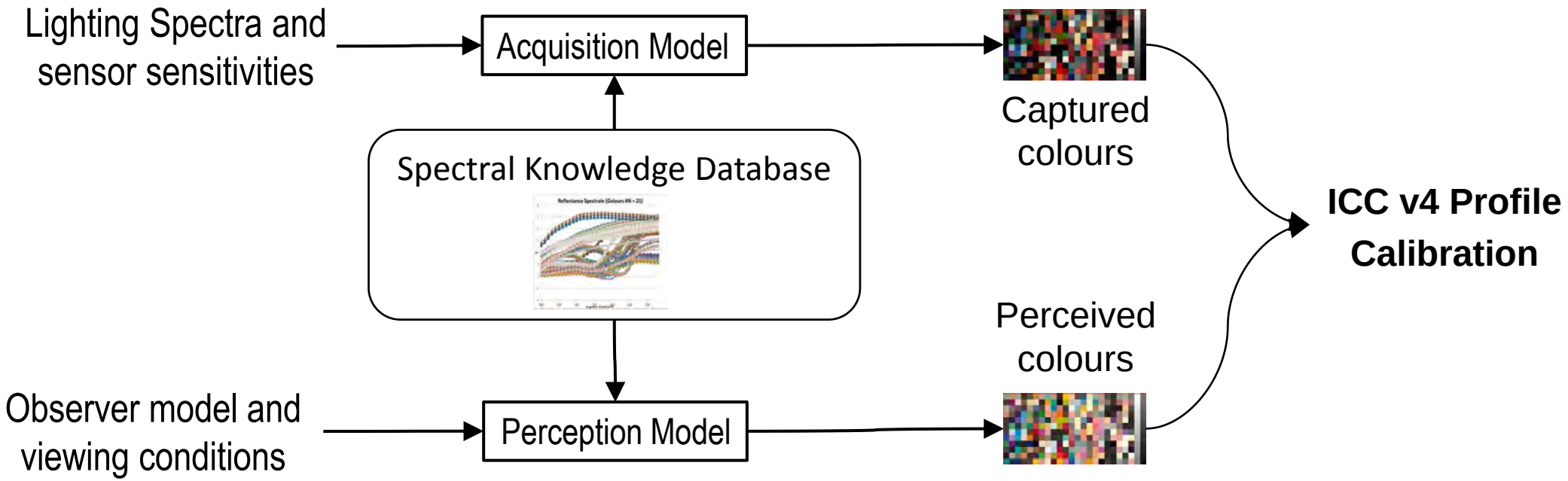


6: Species F
Dark blue to violet



Note that reading scale complexity is for a defined medium (i.e. specific agar). Each medium requires specific color reading scales.

Knowledge Based Spectral Calibration



GOALS :

- Build **a Knowledge Base** of spectral reflectance & transmittance
- **Standardize** spectral reflectance & transmittance measurement **& control** method
- Development or adoption of standards for management of display configurations, for example management and display of out of gamut colours

Skin imaging – Kaida Xiao

At University of Liverpool, working on skin reflectance measurement, estimation and reproduction (e.g. in prosthetics)

At University of Science and Technology Liaoning, we start to arrange skin spectra image database based on camera RGB image and spectra reflectance estimation.

A psychophysical experiment is also in plan to investigate naturalness of facial image using proposed image database and compare spectral estimation performance between different algorithms.