Medical Imaging Working Group

AP Hamamatsucho
2 Chome-4-1 Shibakoen
Minato-ku
Tokyo-to
10 June 2015

Craig Revie, chair of the Medical Imaging WG, opened the meeting at 13:00 and welcomed the on-site and remote attendees. He reminded those present of the Medical Imaging web site, and also showed the VCT software for display calibration testing available from Barco [see attached]. Following self-introductions Mr Revie introduced the agenda as follows:

1. Medical photography
2. iccMAX ICS for medical imaging modalities
3. Whole-slide imaging
4. LED colour generator and its application
5. Westminster University skin colour measurement and display
6. Display calibration mRGB/dRGB

An item on proposed display calibration was deferred to a subsequent meeting owing to lack of time.

1. Medical photography
Dr Phil Green introduced the most recent version of the Medical Photography guidelines and recommended workflow, on behalf of Dr John Penczek [see attached]. Dr Penczek had emphasised that the draft guidelines were based on good practice in professional photography, and that the colour target-based approach was the easiest to adopt within the target user community as it is based on commercially-available equipment. The guidelines only address camera capture and not other imaging modalities. Dr Penczek had also noted that ICC profiling is realistically the only option for open-source camera calibration and he intended to make a stronger case for profile use in the next revision of the document.

2. iccMAX ICS for medical imaging modalities
Interoperability conformance specifications are intended to define restrictions to the iccMAX profile format and architecture for particular use cases. Dr Green introduced the current version of the iccMAX ICS for bioMaterialIdentification [see attached]. This was now using the ISO template, and included the ISO boilerplate material and required sections including introduction, scope, normative references, and terms and definitions. Although not yet final, it was agreed this was an appropriate format for the document.

3. Whole-slide imaging
Mr Revie presented a summary of progress to date on this topic [see attached]. He referred to the presentation by Dr Yagi in Vancouver 2013, which had reported large differences between different scanners and viewing software. Displays also contributed to this variability. Inaccuracies may lead to diagnostic error and reduce efficiency.

Mr Revie listed the calibration methods that had been considered, which were essentially a film-based characterization target, a sensor model, the Datacolor Chromacal approach. He showed the FFEI calibration assessment slide.

He reviewed the open questions and it was agreed that the next steps were to update the test materials and generate a calibration methods document, and then to generate any ICS documents for iccMAX implementation.

4. LED colour generator and its application
Mr Hiroshi Urabe of Shizuoka University introduced the LED colour generator [see attached]. This had been proposed as ISO TS 17321-4, in the camera characterization series.

The characterization method assumes the camera has an IR-cut filter. He showed evaluation methods for light sources, and a characterization example which had achieved an error of less than 1 in CIEDE2000 for the reflectance of selected ColorChecker patches. He showed factors known to have contributed to the errors.

Urabe-san had found that the number of LEDs was important. He recommended at least 10-bit data precision, and proposed that tolerances should be determined independently. He identified a number of application use cases, and suggested that the method could be implemented in iccMAX. One purpose was to reproduce colours of interest to medical imaging, such as skin.

Urabe-san asked for comments and suggestions by email to Hitoshi Urabe <urb_09119@mbr.nifty.com>

5. Westminster University skin colour measurement and display
Dr Efthimia Bilissi introduced a proposed research project on skin colour reproduction on LCD displays [see attached]. The focus of the work was on pathological skin conditions. In her presentation she reviewed comments that had been made in an email discussion. Interested members are invited to contact Dr Belissi at Efthimia Bilissi <E.Bilissi02@westminster.ac.uk>.

6. Display calibration mRGB/dRGB
Dr Tom Kimpe introduced a discussion of the draft recommendations of the ICC MIWG Displays activity [see attached]. Dr Kimpe thanked MIWG members for their input on the draft document, and undertook to distribute a revised version.

The initial focus of the work was on GSDF for colour displays. Ultimately the goal would be to make recommendations for calibration of both greyscale and colour images. It was noted that some instances of colour were annotations, pseudo-colour etc., where a perceptually linear RGB (similar to the GSDF concept) would be applicable. Dr Kimpe emphasised that the discussion should be synchronised with the emerging dRGB standard, for example by defining a tag to indicate whether a display was PLCB.

A key point in the draft recommendations is a 10% tolerance, based on current practice. This is specified in the AAPM document, defined as $\Delta L/L$.

The meeting gave feedback on the approach. It was noted that there must be an accurate black point measurement. Yamaguchi-san asked whether there would be different levels of compliance. It was emphasised that the scope is monochrome DICOM images, but with support for colour on hybrid displays.

Chris Bai of Ben-Q asked what the display requirements were. Dr Kimpe agreed to point to existing standards and minimum requirements for medical displays in the document. It was also noted that the native white point chromaticity is a medical display would probably not be D50, and Media-relative colorimetric rendering should be used to map the actual display white point. The need to address the recommended rendering intent was noted.

Dr Kimpe proposed approval of the guidelines so that they could be presented at the AAPM conference in July. The next step was to continue working on the PLCB concept.

Mr Revie suggested that there was consensus on the overall picture, although there were some smaller points to resolve. He proposed that Dr Kimpe go ahead with the AAPM presentation.

Mr Revie thanked all the participants for their attendance and reminded them of the next meeting in San Jose in October. The meeting closed at 5:00pm.

Action items

Medical photography
MIWG-15-10 Continue work on medical photography guidelines (Penczek)

iccMAX ICS for medical imaging modalities
MIWG-15-11 Continue work on ICS document (Green)

Whole-slide imaging
MIWG-15-12 Update the test materials (Revie)
MIWG-15-13 Generate a calibration methods document (Revie)
MIWG-15-14 Generate any ICS documents for iccMAX implementation (Revie, Green)

Display calibration mRGB/dRGB
MIWG-15-15 Present proposed guidelines at AAPM meeting (Kimpe)

International Color Consortium

ICC Medical Imaging Working Group

Tokyo

10th June 2015

ICC: EVENTS:

All ICC Events

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 Developer Conference: iccMAX

DevCon iccMAX Q&A session

Video of DevCon iccMAX

Medical Imaging WG, Nov 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
DICOM camera raw support and EXIF tags
Petri plate calibration
Open source reference implementation
Best practice papers for colour in DICOM

Summary of all MIWG **work items**

Upcoming MIWG meetings

Date	Location	Topic
8-10 Jun 2015	Tokyo	Full WG meeting

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

Previous meetings
Meetings and minutes
Action items

SEARCH ICC : GO

Got a question about ICC Profiles or colour management?

Ask Phil...

ICC: LIVE TOPICS:

iccMAX

ICC Medical Imaging Working Group

Display calibration

New PRMG-based exchange profile for digital print

Profiling tools

ICC Profile Registry

sRGB profiles

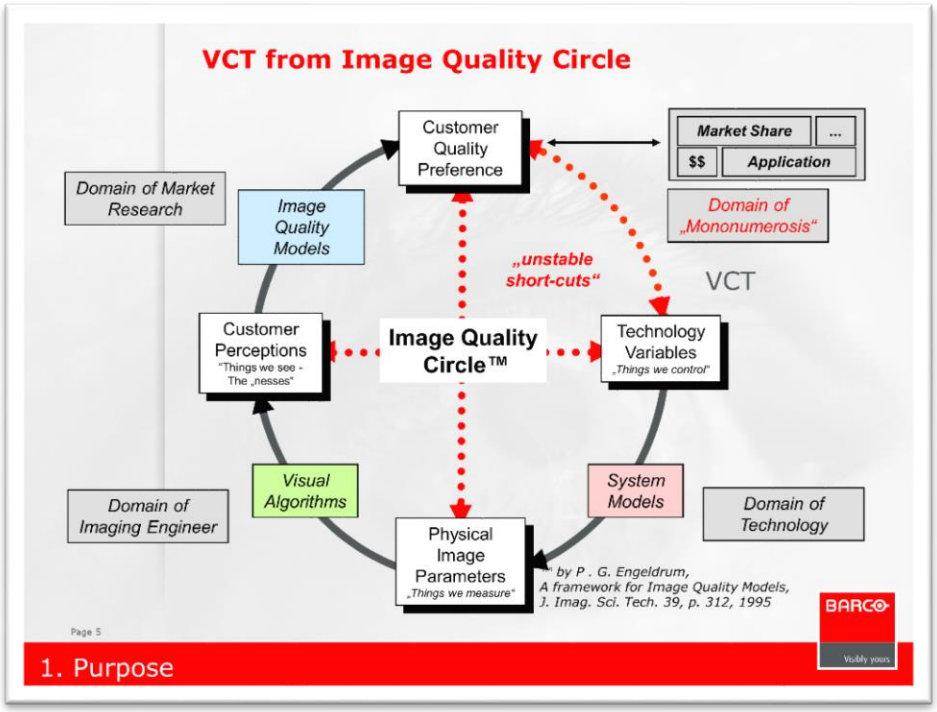
ICC user forum

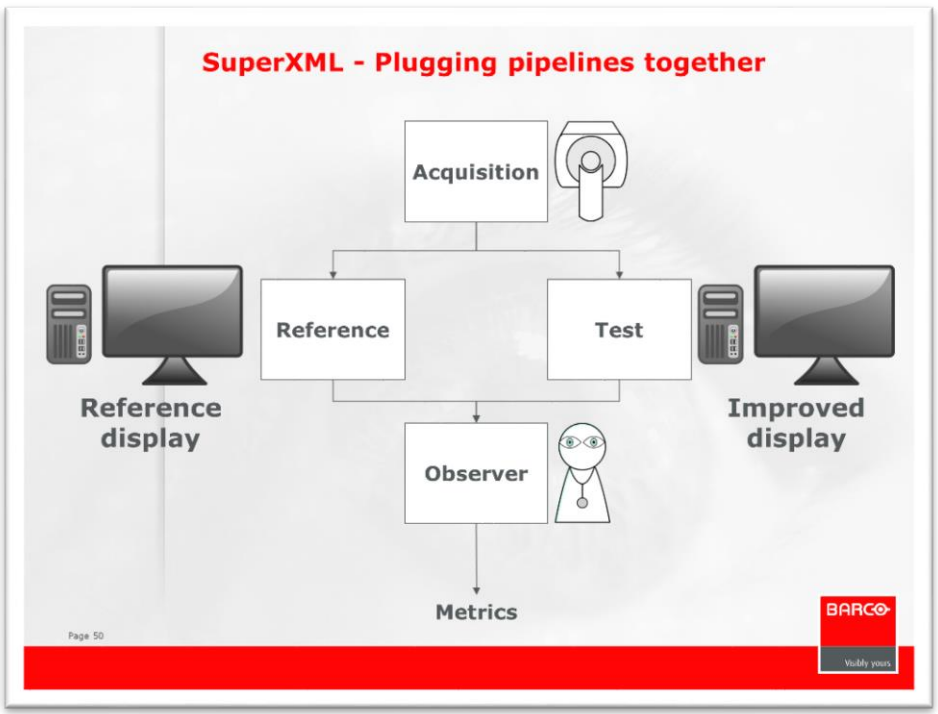
Membership benefits

What is an ICC Profile?

What is FOGRA39?

VCT software





- **The VCT software can be found at https://github.com/Barco-VCT/VirtualClinicalTrials**
- **All documentation is available at https://github.com/Barco-VCT/VirtualClinicalTrials/tree/master/doc**

ICC MIWG Working group meeting

Wednesday 10th June, 13:00-17:00

1. Medical Photography	Phil Green
2. iccMAX ICS for medical imaging modalities	Phil Green
3. Whole Slide Imaging	Craig Revie
4. LED colour generator and its application	Hitoshi Urabe
5. Westminster University skin colour measurement and display	Efia Bilissi
6. Display calibration mRGB / dRGB	Tom Kimpe

Deferred

Proposed display calibration testing	Craig Revie

Recommended Image Capture Workflow for Medicine Photography

John Penczek

March 24, 2015

Introduction:
This general procedure outlines a recommended digital camera image capture workflow that can be used to improve image color accuracy and consistency. The process it outlined in the flowchart given in Annex A. The implementation of this workflow would be especially beneficial for use cases where color accuracy is critical, such as dermatology, plastic surgery, pathology, and wound documentation. It should also be noted that since medical photographs are part of a patient's record, they are subject to privacy considerations.

Required equipment:

- Digital color camera with white balancing capability.
- Reference color test chart. May be a commercial color chart (e.g. from X-Rite, DSC Labs, QPcard, Douglas color card, etc…) or one designed for the application. The color chart should come with the corresponding measured color data.
- Light source and background that can provide uniform hemispherical illumination over the camera field of view. The light source should produce spectrally smooth broadband white light, approximating daylight. Spectrally "spiky" spectra can produce problems.
- Color correction software that can recognize each color in an image of the reference color chart and create a calibration profile (HSL Preset file, DNG or ICC profile, or similar), which can be used to color calibrate an image of an object photographed under the same conditions as the reference color chart. Color correction software that does not save calibration files should embed the calibrated RGB values in the image and export it as an sRGB image.

Desirable equipment:

- Digital color camera capable of exporting RAW image files, and the ability to perform an in-camera white balance. The camera should be flat-field corrected to within 2%.
- A RAW file decoder/converter which is able to import RAW images and export them as $\geq$12-bit TIF or DNG format. Commercial software (e.g. Adobe camera RAW, Capture One, Phocus, etc…) is available, as well as open source software (such as Dcraw).
- Software that can import DNG, TIF, or similar images and perform a correction for illumination non-uniformity and white/gray balance.
- It is recommended that the color correction software provide ability to create ICC profiles. Commercial ICC-aware viewing software is available from several companies, in addition to free software (e.g Irfanview and GIMP).

Procedure:

Image capture

1. Setup up the illumination and background for photographing the object of interest. The background should be a uniform matte color, ideally a gray with 20% reflectance. The camera field of view, shall be adjusted so that it does not extend beyond the gray background. This field of view should be fixed for all photographs.
2. The light source should produce uniform diffuse hemispherical illumination over the field of view, with special attention paid to the lighting uniformity over the image area where colors will be evaluated. This will minimize glare, specular reflections and errors arising from lighting non-uniformity. Examples of diffuse lighting configurations are given in Figure 1.

Figure 1. Example of diffuse lighting setups using commercial softbox lighting (left), or a homemade lightbox with diffuse walls (right).

3. The object of interest and/or reference color chart will define the image region of interest (ROI). For the side-by-side method, the ROI is defined by the object of interest and the color chart placed adjacent to it. In the sequential method, the ROI is defined by the object of interest or the color chart, whichever is larger. Place a uniform diffuse (ideally 20% reflectance) target in the image plane at the ROI. If the gray target is large enough to fill the entire ROI, then it may be used to compensate for illumination non-uniformity during the image post-processing.
4. Position the camera in front of the gray reference and align the camera so that its optical axis is centered on the gray reference and perpendicular to it. The image ROI should be contained within about half the field of view of the camera. If the sequential method is used, it is best to use a tripod, or similar mechanism, to hold the camera stationary for the remainder of the photographs. If the side-by-side method is used, then a fixture similar to that shown in Figure 2 can be used. The side-by-side method is preferred if the illumination is not stable.
5. Use the in-camera white balance function to determine the proper white balance for this lighting condition, and maintain this white balance setting for all subsequent photographs. Some cameras have a Preset Manual or Custom white balance mode to

obtain and hold that white balance setting. Omit this step if the camera does not have in-camera white balance capability.

Figure 2. Example fixture used for the side-by-side image capture method.

6. Capture the image of the gray reference in the ROI. If the illuminance is not uniform in the ROI to within 5%, an illumination non-uniformity correction should be applied in the image post-processing. This correction is only valid if the camera setting and lighting conditions are held constant.
7. Place the reference color test chart in the focus plane of the ROI, so that the camera field of view captures all of the colors in the chart. For the sequential method, the optical axis of the camera should be centered on the chart and perpendicular to it. For the side-by-side method, the edge of the color chart is positioned near the center of the camera image (see Figure 3). Photographic test charts (such as ColorChecker SG can be used, although ideally patches should be matte rather than gloss. Custom charts with patches constructed to be similar to the subject of the photography can also be used (e.g. PANTONE SkinTone™ Guide from X-Rite or Douglas color card may be used for skintones).
8. Set the camera exposure that the lightest color patch in the test chart is approximately 90% of the camera saturation white.
9. For the sequential method, capture the image of the reference color test chart and export the image in RAW file format, if the camera is capable. Where possible, use a "neutral" mode RAW capture setting, which minimizes any camera visual enhancements. Replace the reference color test chart with the first object to be photographed, center in the image, and capture the image of the target object. Repeat the image capture of subsequent objects in turn (see Annex A). Export the images in the same RAW file format. The lighting conditions and camera settings should not be changed. If the camera cannot export RAW files, set the camera to use the highest quality (least compression) image, use low ISO values, and export sRGB images.
10. For the side-by-side method, place the color chart adjacent to the object of interest (see Figure 3) and capture the image using the "neutral" mode RAW capture setting. Export the image in the RAW file format if possible. Replace the first object of interest with other objects in sequence at the same focus plane. The lighting conditions and camera settings should be unchanged. If the camera cannot export RAW files, set the camera to

use the highest quality (least compression) image, use low ISO values, and export sRGB images.

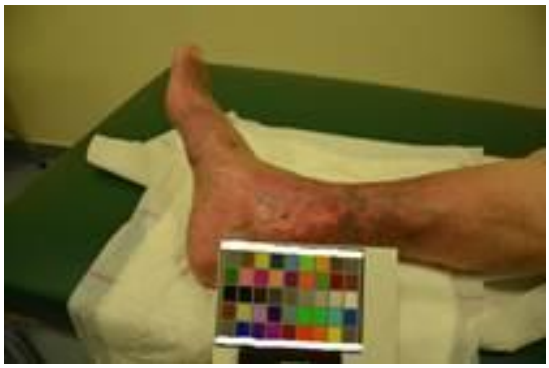


Figure 3. Example alignment of the side-by-side image capture method.

Color correction

1. For RAW files, use a RAW image converter/decoder to extract the image information in all files and save them in a standard image format (e.g. ≥12-bit color TIF, DNG, or similar files). The file should include the desired white balance.
2. If an illumination non-uniformity correction is deemed necessary, apply the uniformity correction to all reference color chart and object images.
3. Open the image of the reference color chart (for the sequential or side-by-side method). Use the program to ensure that the gray levels are scaled correctly. The graylevel scaling will depend on the reference color chart used. However, it is common to use a reference color chart where the whitest color patch is set to an exposure of 90%, or RGB= 230, 230, 230 for 8-bit RGB color images. Then the darkest patch is set to an exposure of 4%, or RGB= 10, 10, 10. If the black patch is below this level, then use the current setting or reshoot the photograph with brighter illumination. For the sequential method, the graylevel scaling applied to the reference color chart is also applied to all object images taken under the same shoot conditions.
4. The color-correction software should automatically find the centers of each color patch of the greylevel-scaled reference color chart image, and create an HSL Preset or color calibration profile (DNG, ICC profile, or similar) based on the known color values of the reference chart. It is recommended that ICC profiles also be created, if it is not already the primary color correction pathway.
5. For the side-by-side method, apply the HSL Preset or color calibration profile to the image and save the new color-corrected image in the desired format (e.g. a high quality TIF file). Repeat the graylevel scaling and color-correction for each side-by-side image. An example of a color-corrected image is shown in Figure 4.

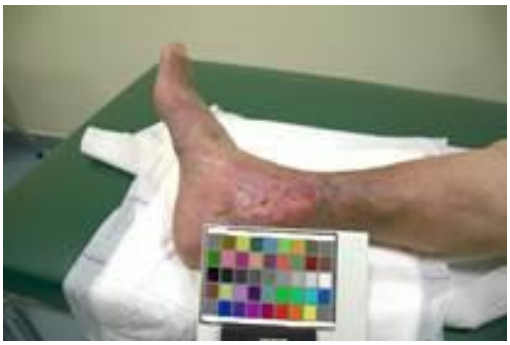
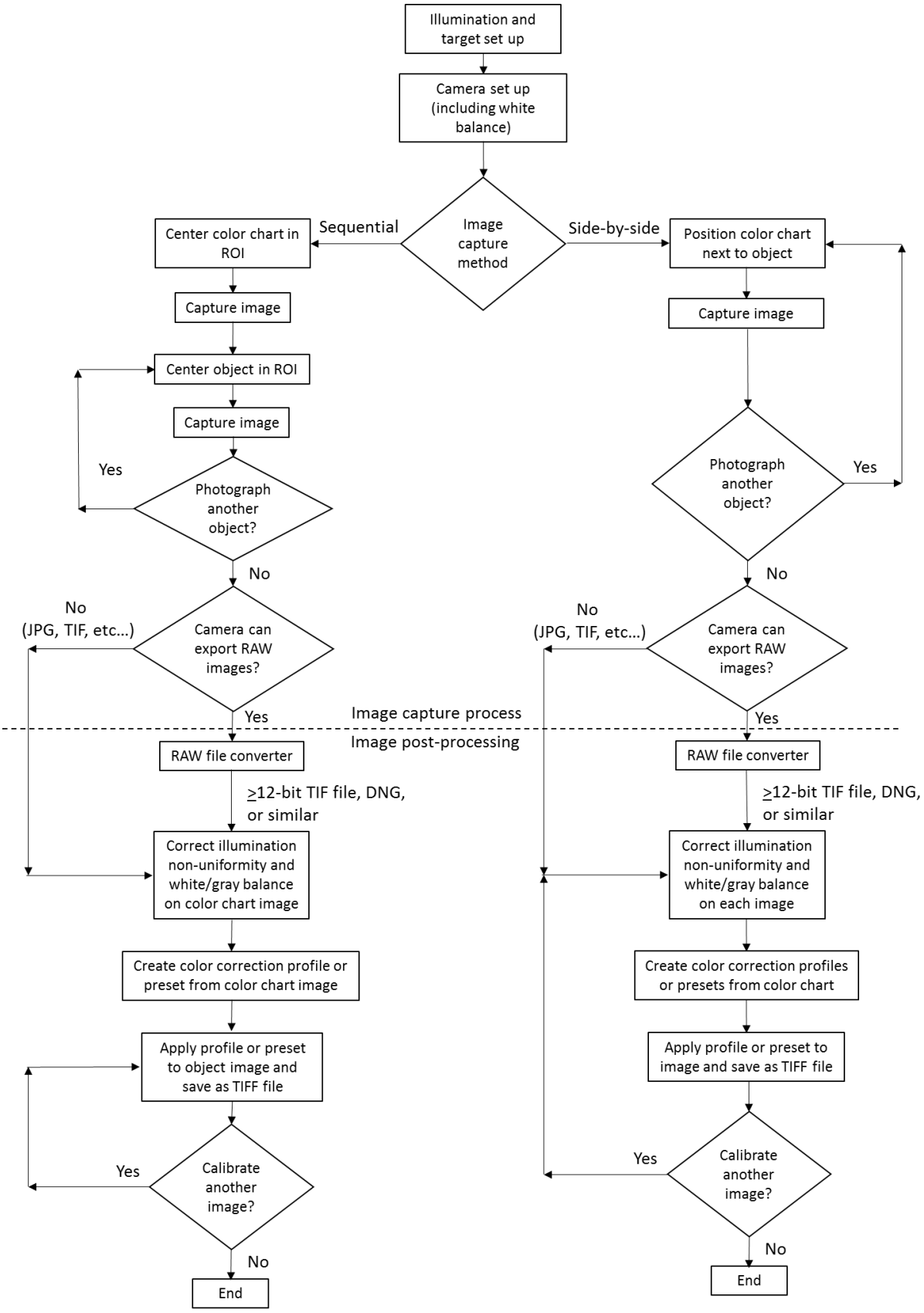


Figure 4: Example of color-corrected image using Figure 3 following the side-by-side method.

6. For the sequential method, import the other photographed objects of interest into the image editing program that is capable of using HSL Presets or color calibration profiles. Apply the HSL Preset or color calibration profile to each image and save the new color-corrected image in the desired format (e.g. a high quality TIF file).

Acknowledgement:
The authors would like to thank Yves Vander Haeghen and Dienst ICT at Universitair Ziekenhuis Gent for sharing the figures used in this article.

Annex A
Flowchart of Camera Image Capture and Color Correction Workflow



International Color Consortium

Image technology colour management — Extensions to architecture, profile format, and data structure — — Part #: Interoperability Conformance Specification: bioMaterialIdentification

Contents

Introduction

ISO xxxxx-1 defines specifications that provide a platform for defining extended (iccMAX) colour management profiles and systems for various colour workflow domains. It provides a platform for which domain specific specifications can be defined that make use of iccMAX extensions to the existing cross-platform profile format of ISO 15076-1. Thus there is greater flexibility for defining colour transforms and profile connection spaces to meet needs that cannot easily be met with ISO 15076-1. It is not envisioned that all colour management systems that use ISO 20677-1 will implement all the features or capabilities it specifies. Requirements specifying restrictions to iccMAX that apply to a particular workflow are defined in workflow domain specifications known as Interoperability Conformance Specifications, of which this document is an example. Additionally, for some domain specific workflows it is envisioned that workflows will connect to both profiles defined by ISO 20677-1 (iccMAX) and those defined by ISO 15076-1.

ISO 20677 Image technology colour management — Extensions to architecture, profile format, and data structure — — Part #: Interoperability Conformance Specification: bioMaterialIdentification

1 Scope

This International Standard defines workflow requirements and restrictions to profiles based on ISO 20677-1 for the purpose of determining and visualising material amounts from a digital image.

Domain-specific Interoperability Conformance Specification (ICS) documents, of which this document is an example, are approved and registered by the ICC. They define minimum structural and operational requirements for writing and reading ICC profiles in order to address a specific problem and/or functionality that cannot readily be handled using the profile format defined by ISO 15076-1. An ICS document essentially defines restrictions to ISO 20677-1 for a specific use case.

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 20677-1:20##, *Image technology colour management — Extensions to architecture, profile format, and data structure1: iccMAX*

3 Terms and definitions

3.1
biomarker
measurable indicator of some physiological state of an organism

NOTE: Other definitions relevant to this document are provided in ISO 20677.

4 Use case

The intended use of this specification is to define workflows in which multichannel input data is connected to a Material Connection Space (MCS) and from there to output device channels or to a Profile Connection Space (PCS).

This ICS defines requirements for ICC profiles whose primary purpose is to convert from multichannel input data to biomarker amounts in a material connection space, and subsequently convert to channels in an output device or to a colorimetric visualization.

4.1 Restrictions

ISO 20677-1 provides full details of the requirements for iccMAX profiles. This document defines a set of restrictions which apply to profiles created for the specific use case described in 4. above.

5 Requirements

5.1 Domain

Profiles and workflows conforming to this part of ISO 20677 shall apply to the domain of Medical Imaging.

5.2 Profile Class

Profiles conforming to this part of ISO 20677 shall have the class of Material Input (signature 'mid '), Material Link ('mlink') or Material Visualisation ('mvis').

5.3 Profile Sub-class

The profile sub-class shall be bioMaterialIdentification (signature 'bmid').

5.4 Header

The encoding of the profile header shall be as defined in ISO 20677-1, with the specific requirements shown in Table 1.

Table 1. Header requirements

Header field	Required content
Profile class	'mid '
Profile subclass	bioMaterialIdentification 'bmid'
Profile subclass major version	1
Profile subclass minor version	0
Data colour space	'ncxxxx' where xxxx is the number of channels of the data encoding
MCS	'mcxxxx' where xxxx is the number of channels of the MCS
Colorimetric PCS	0
Spectral PCS	0
Bispectral PCS	0

Full details of the encoding of the header fields in Table 1 are given in ISO 20677-1.

5.4 Required tags

Profiles shall contain the tags listed in Table 2.

Table 2. Required tags

Tag name	Signature	Required content
AToM0Tag	'A2M0'	multiProcessElementType containing transform from data colour encoding to material connection space. This transform will normally be a xxxx x n matrix, where xxxx is the number of material channels of the MCS and n is the number of channels of the input data encoding
materialTypeArrayTag	'mcta'	An array of material type names for each channel in the Material Connection Space for the purpose of profile connection
materialDefaultValuesTag	'mdv '	A uint8, uint16, float16 or float32NumberArray which defines a default material value for each channel identified in the materialTypeArrayTag.

The encoding of the tags listed in Table 2 shall be as defined in ISO 20677-1.

6 Workflow

A bioMaterialIdentification profile shall connect n input channels (where n is the value encoded in the Data colour space field of the header) to a Material Connection Space containing m channels (where m is the value encoded in the MCS field in the header).

In workflows using the bioMaterialIdentification profile, the MCS channels shall be capable of connecting to output device channels via an MLNK profile, and optionally to a colorimetric PCS via an MVIS profile. Examples of such workflows are shown in Figures 1 and 2 below.

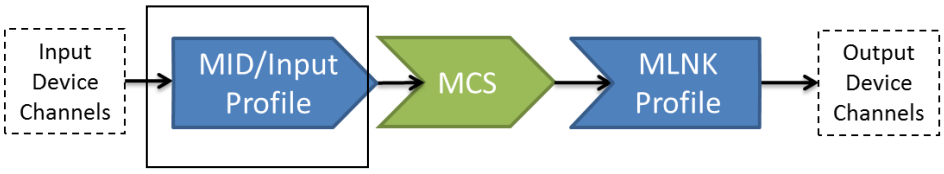


Figure 1. Workflow connecting bioMaterialIdentification profile to MCS and output device

Figure 2. Workflow connecting bioMaterialIdentification profile to MCS and subsequently to colorimetric PCS and output device

Bibliography

[1] ISO #####-##:20##, *General title — Part ##: Title of part*

Whole Slide Imaging Colour Calibration

the story so far

W Craig Revie

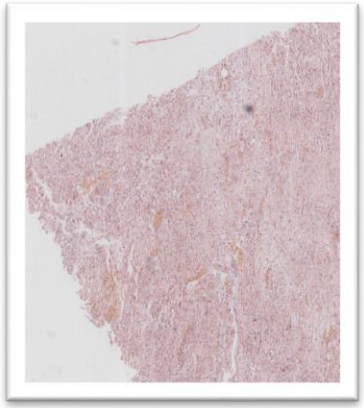
Wednesday 10th June 2015

Outline

- Problem summary
- Review of calibration methods
- Sierra calibration assessment
- FDA draft guidance review and comment
- Next steps

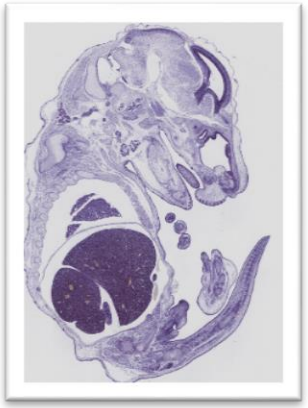
Problem summary

Colours of pathology

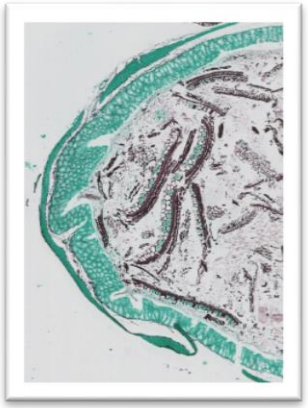


Congo red stain for amyloid

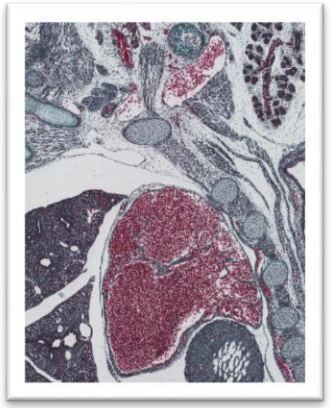
Grocott



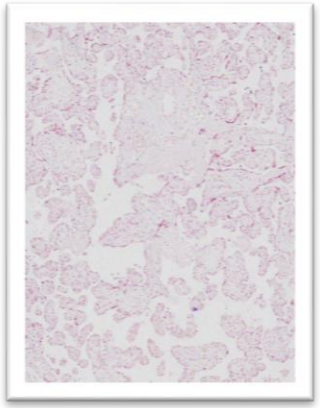
H&E



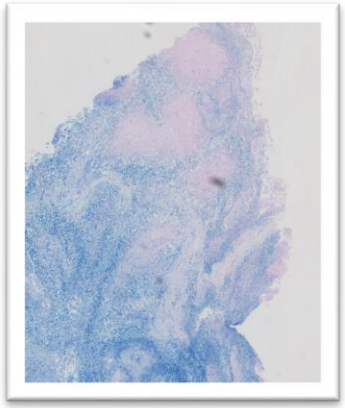
Jones silver stain



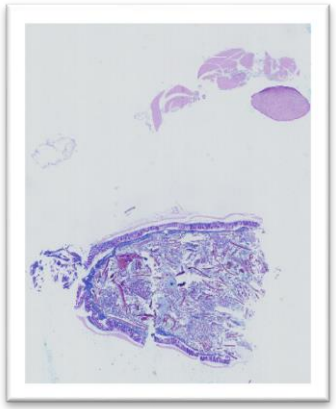
Masson trichrome



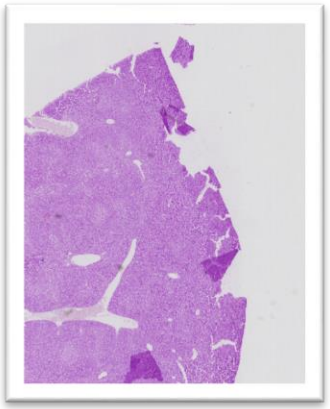
Gram



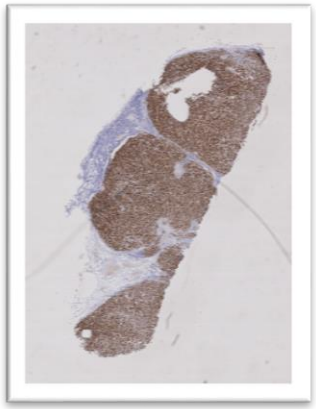
Ziehl Neelsen



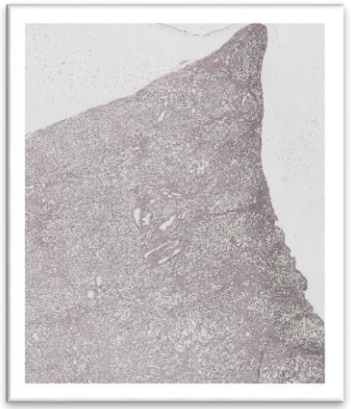
Alcian blue PAS



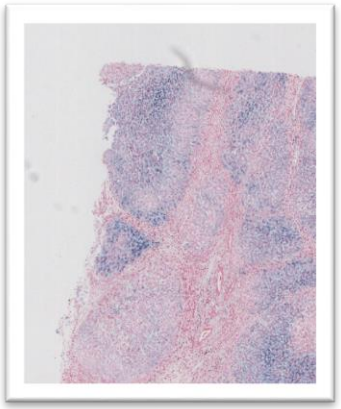
Periodic acid-Schiff (PAS)



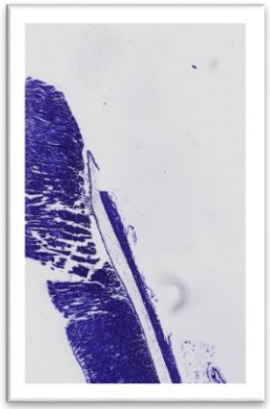
H-DAB



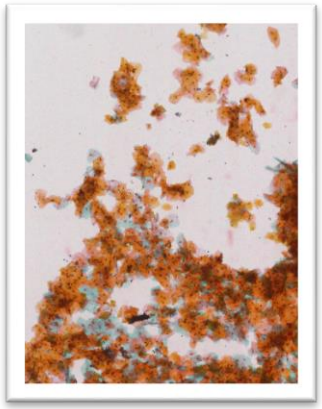
Reticulin



Perls' Prussian blue



Giemsa

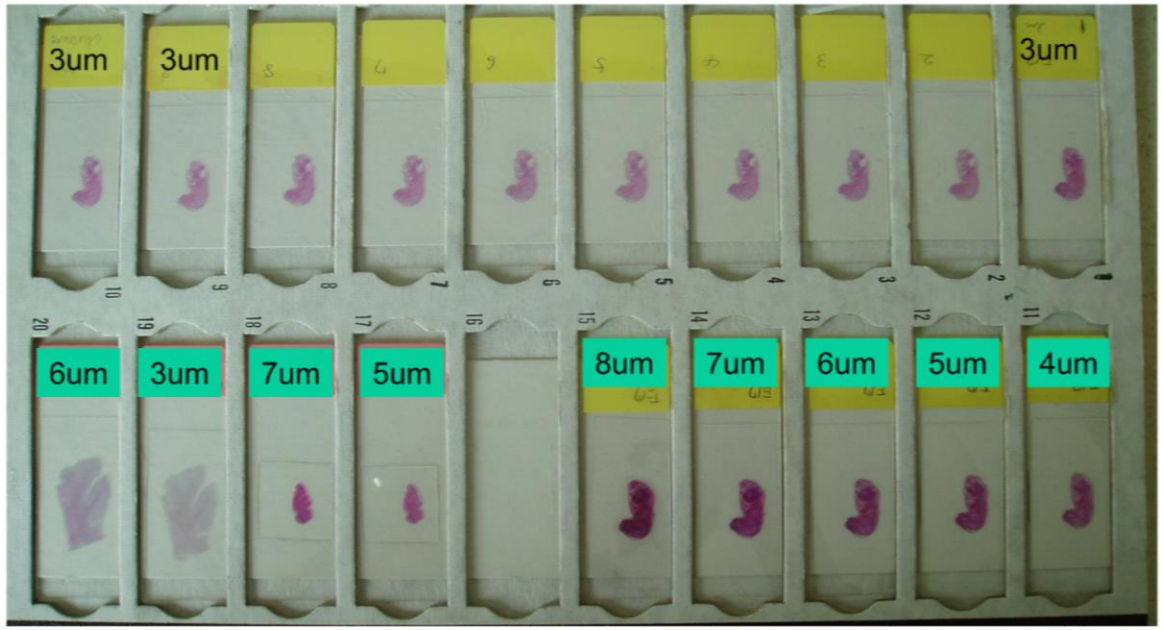


Papanicolaou (PAP)

Yukako Yagi, Vancouver 2013

Thickness of Specimen & Staining

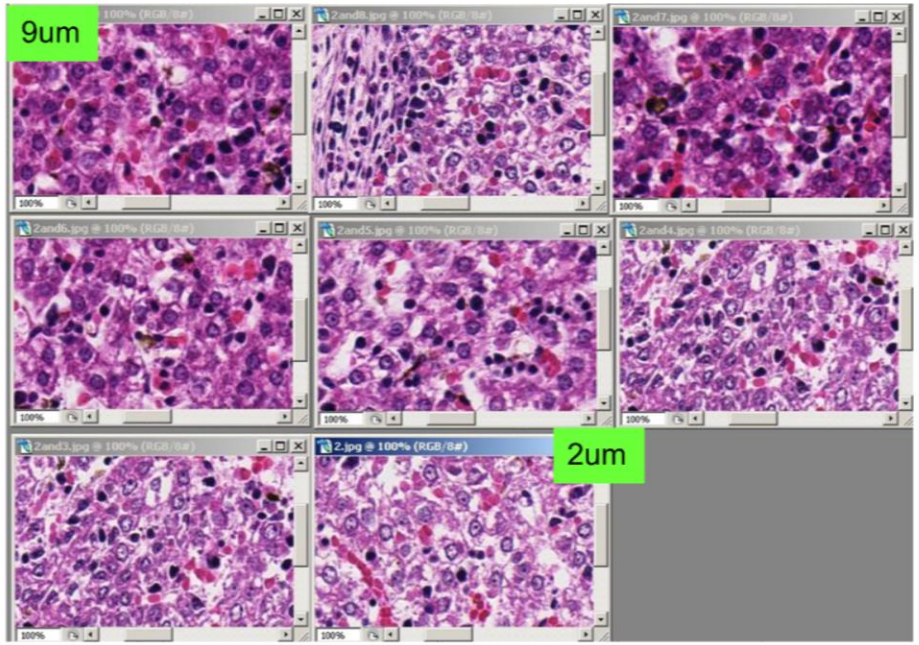
Thicker sections are stained more by the automated staining machine



MASSACHUSETTS GENERAL HOSPITAL PATHOLOGY

HARVARD MEDICAL SCHOOL

Thickness of Specimen & Staining



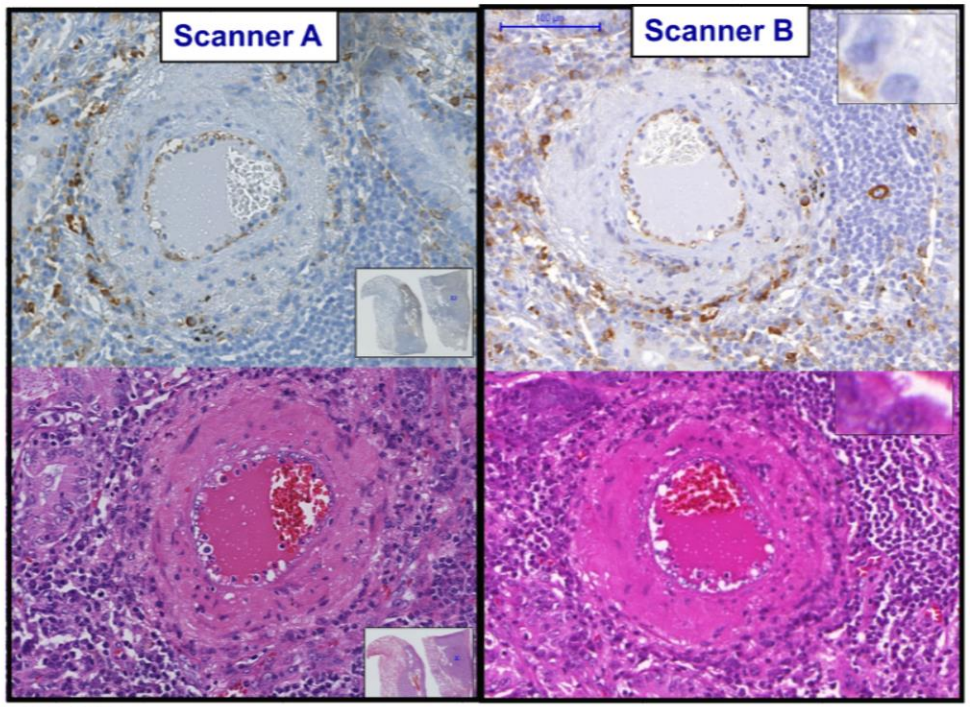
More details can be seen on slides of thinner sections

MASSACHUSETTS GENERAL HOSPITAL PATHOLOGY

HARVARD MEDICAL SCHOOL

Yukako Yagi, Vancouver 2013

Scanner or Scanning Process

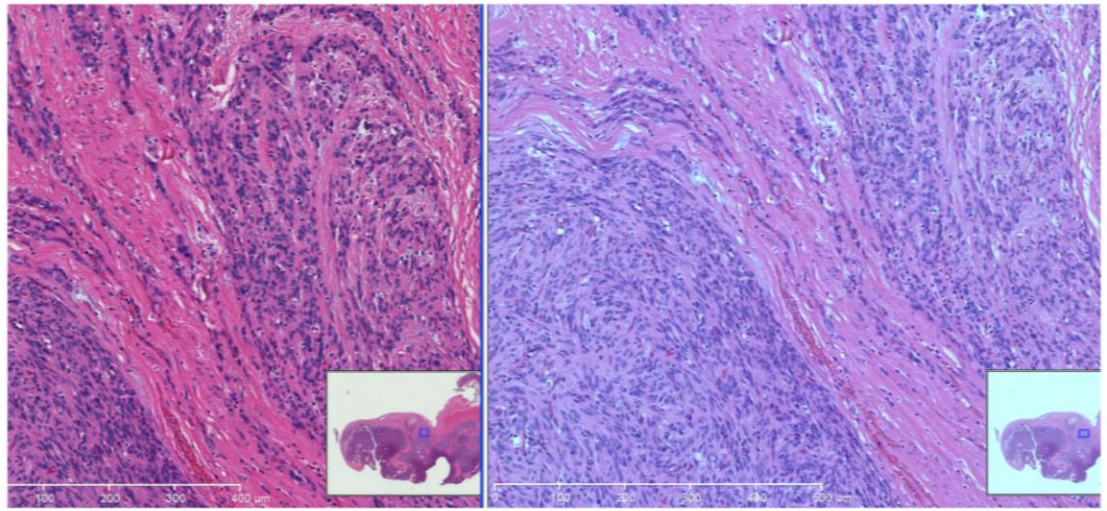


MASSACHUSETTS GENERAL HOSPITAL PATHOLOGY

HARVARD MEDICAL SCHOOL

Viewer Software

Same scanner, same slide, two different viewers



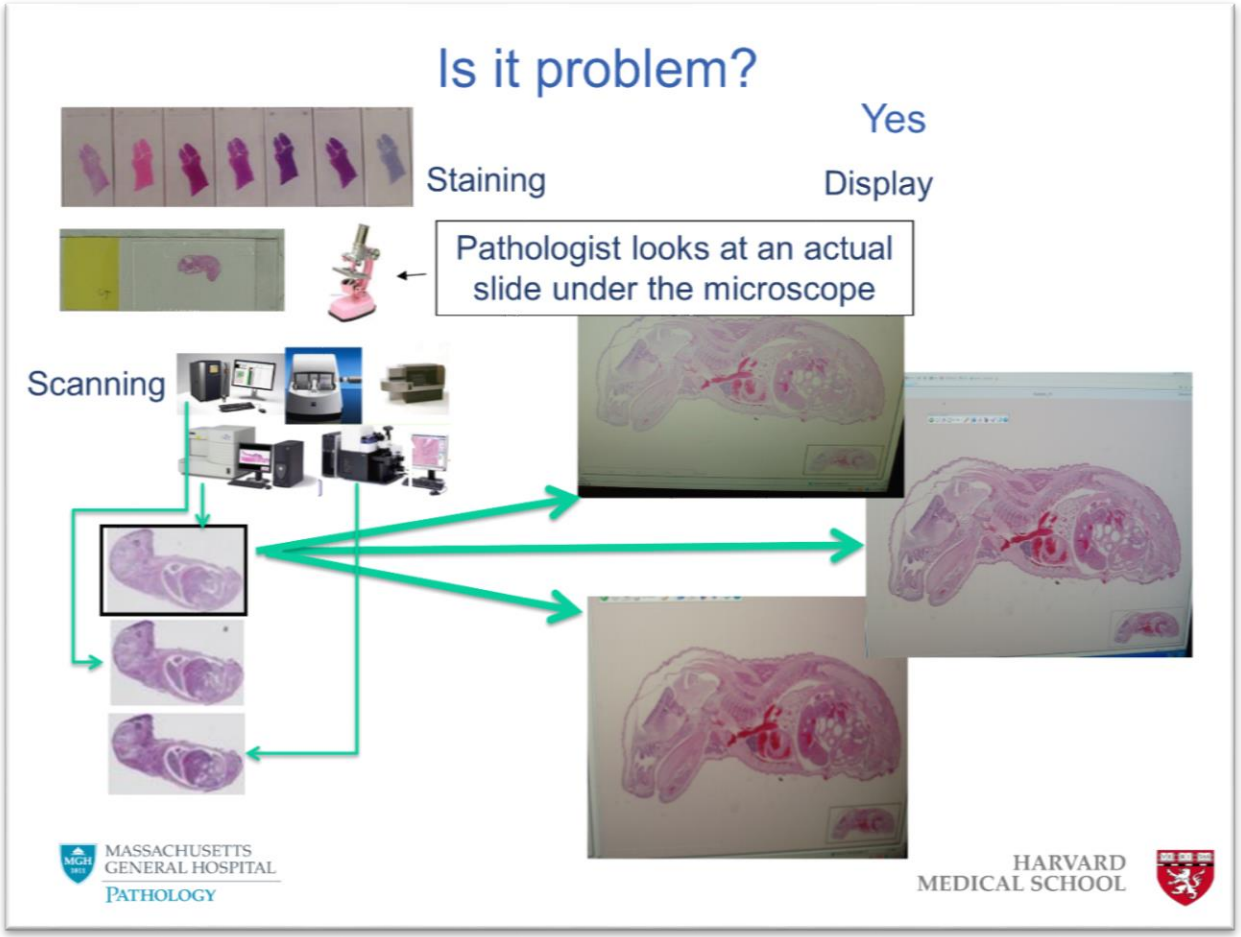
MASSACHUSETTS GENERAL HOSPITAL PATHOLOGY

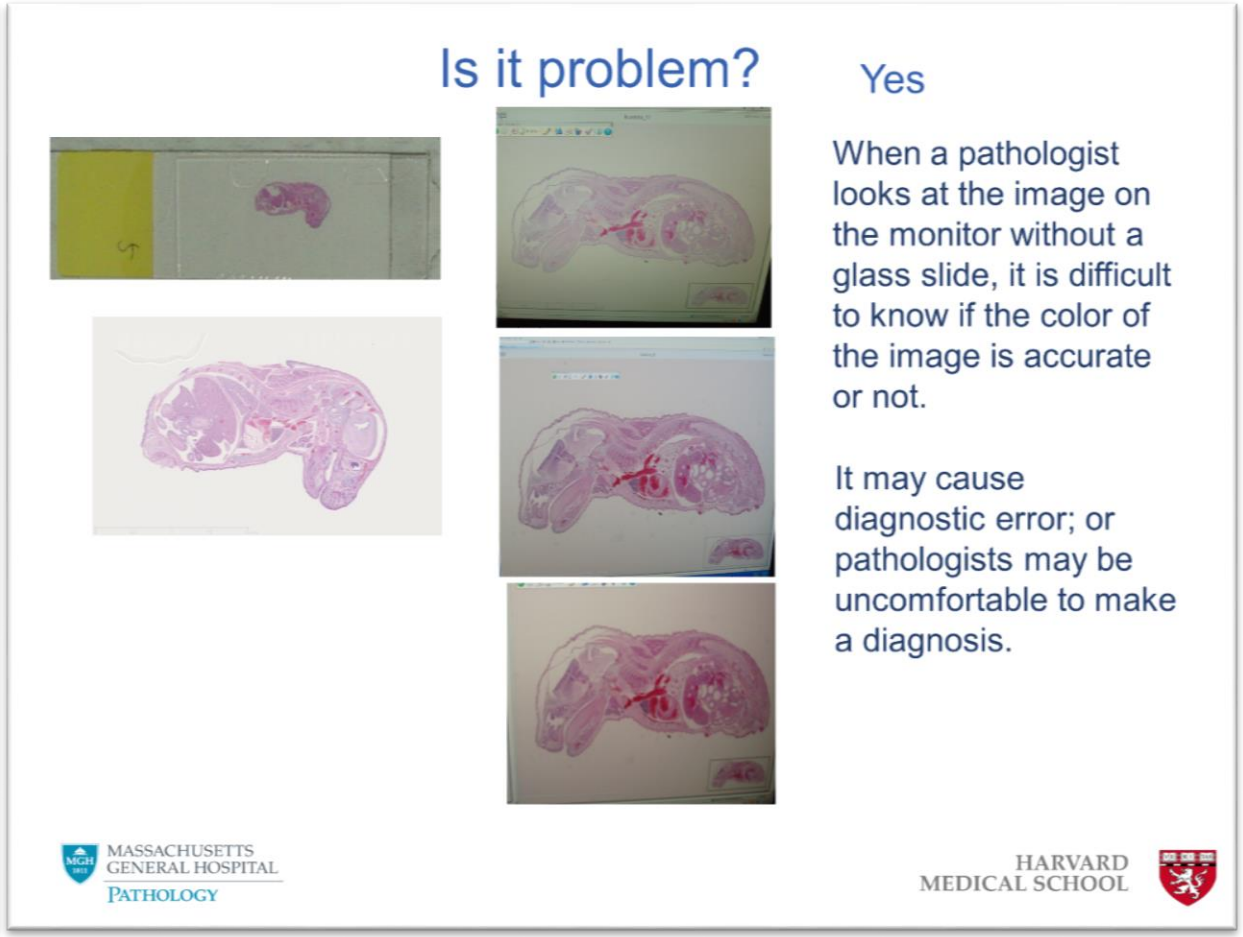
HARVARD MEDICAL SCHOOL

Yukako Yagi, Vancouver 2013

Same image in same PC was viewed by 3 different displays

Yukako Yagi, Vancouver 2013





Problem summary

- Colour processing in Whole Slide Imaging systems varies significantly
  - The same slide scanned on two different systems produces different images
  - The same imaged viewed using two different viewers produces different display colour
  - Although pathologists can adapt to such variation studies have shown that poor colour presentation increases the time reach a diagnosis
  - Automated analysis of images (by computer software) may be more seriously affected by poor colour calibration
- Related problem - variation in staining
  - The process of staining tissue varies from lab to lab and possibly from region to region
  - There is no reference on the slide that can be used to determine staining intensity
  - This variation is not such a problem for pathologists using an optical microscope as they can view the slide directly but for Whole Slide Imaging the slide is usually not available

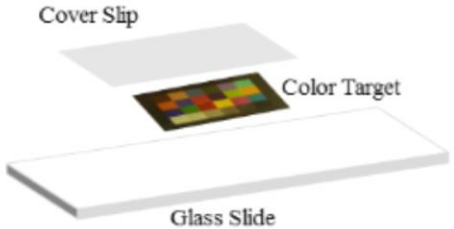
Review of calibration methods

Calibration methods: film target

Color Target Slide for Microscopy

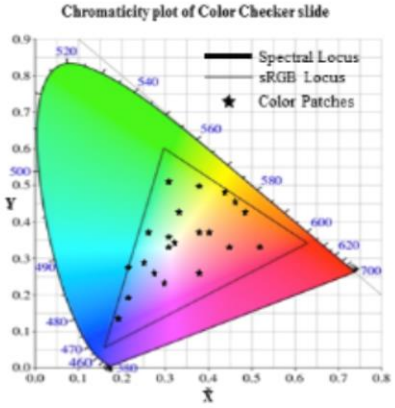
Color Target Film

Target Slide Assembly



Reference Values

Measure (NIST) and plot reference values of each color patch



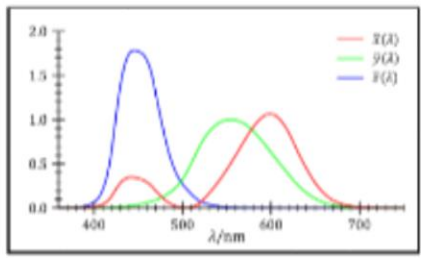
Pros and cons

SequelCsi

- Film targets are routinely made (Pro)
- Film targets can be calibrated (Pro)
- Film targets have limited spectral content (con)
  - Generally only three dye components.
- Film targets may have different scattering properties than (con)
- The optical geometry used to calibrate may not simulate the optical geometry of the scanner (potential con)

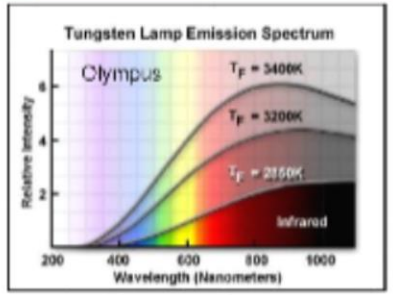
Calibration methods: sensor model

International Color Consortium — Spectral Model for Microscope



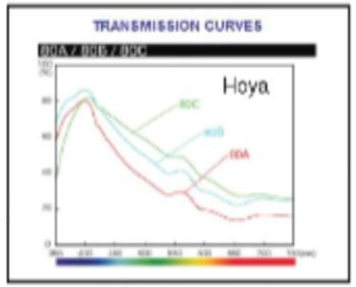
CIE Standard Observer

$< \bar{x}(f), \bar{y}(f), \bar{z}(f) >$



Tungsten Lamp

$L_m(f)$



Daylight Filter

$F(f)$

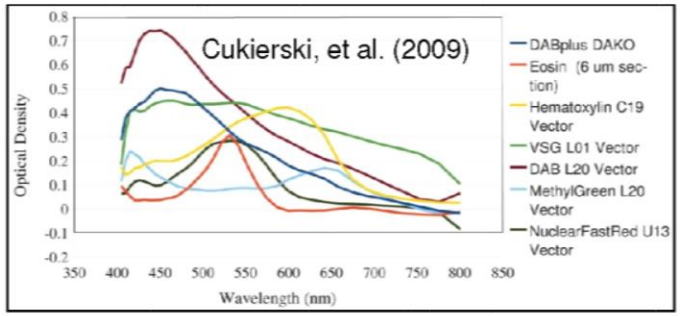
$$< X, Y, Z > = \frac{1}{W_y} \int < \bar{x}(f), \bar{y}(f), \bar{z}(f) > L_m(f)\, F(f)\, T(f)\, df$$

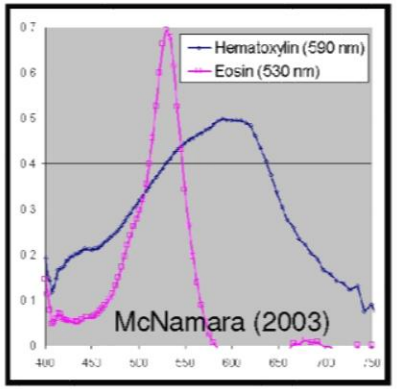
$< X, Y, Z >$
CIE Tristimulus Values

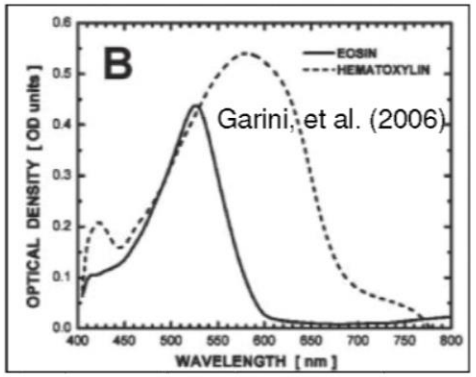
W_y
Normalization
$(Y_{max} = 1)$

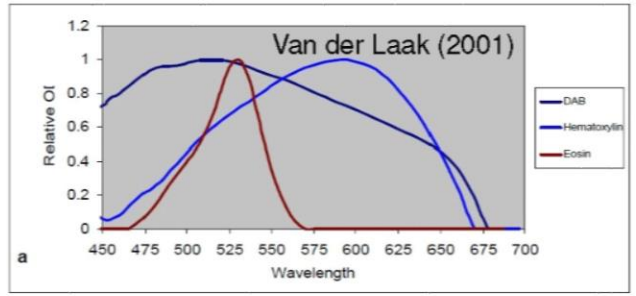
$T(f)$
Stain Transmission Spectra

International Color Consortium — Histological Stain Spectra $T(f)$





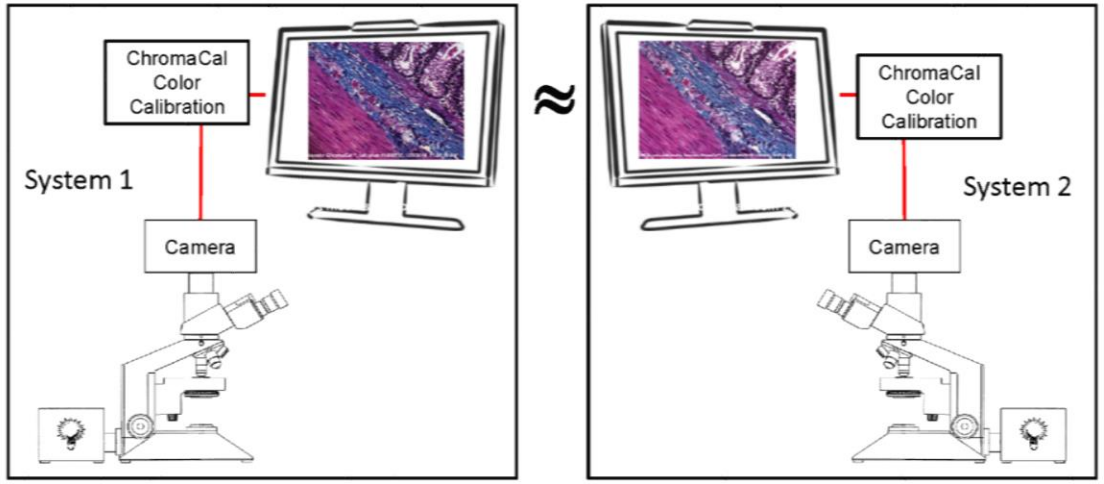




Calibration methods: ChromaCal

Creative Imaging Technology

Color management solution with ChromaCal



ChromaCal™ 11 datacolor

The ChromaCal Workflow

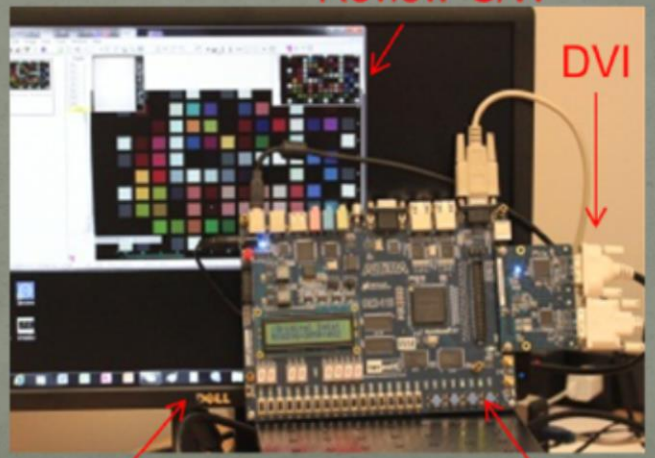
- **Step 1**
  - Capture your specimen images and an image of the calibration slide

ChromaCal™ 13 datacolor

Calibration methods: display

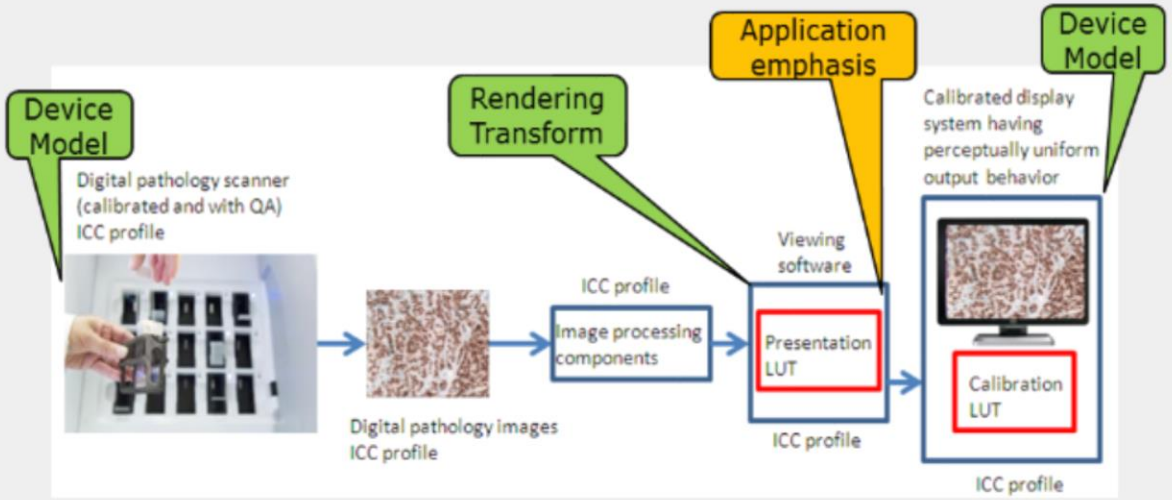
VDCP (SID 2012)

- Virtual Display Color Processor
- A circuit for retrieving RGB values from the DVI or HDMI cable
- Robust digital reading without time-consuming optical measurement
- Account for effects of review software/hardware and color management
- Display can be evaluated as a separate, swappable component



4

Discussion



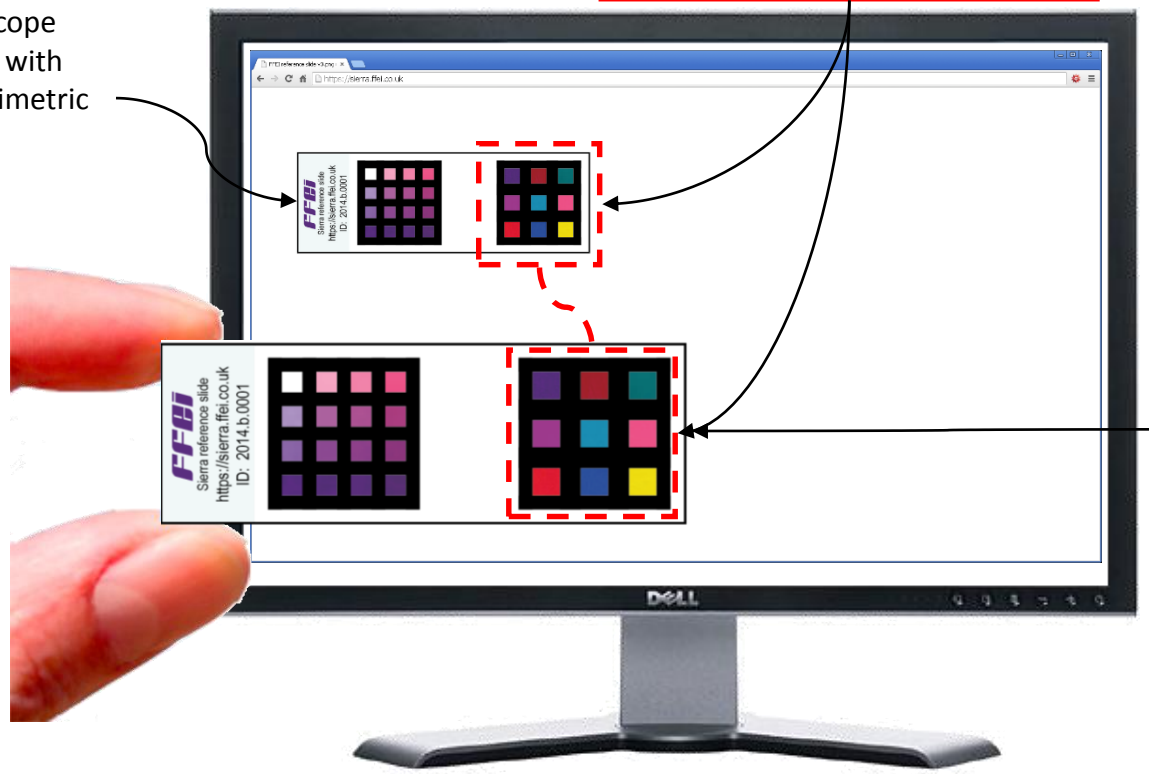
-> Barco would like to work together to prepare a *flexible* imaging chain that enables *interchangeable* and *unequal* components

Slide 20

Visual assessment

System should only be used to view digital microscope slides if these two sets of colours are closely matched

Digital microscope image of slide with Relative Colorimetric rendering

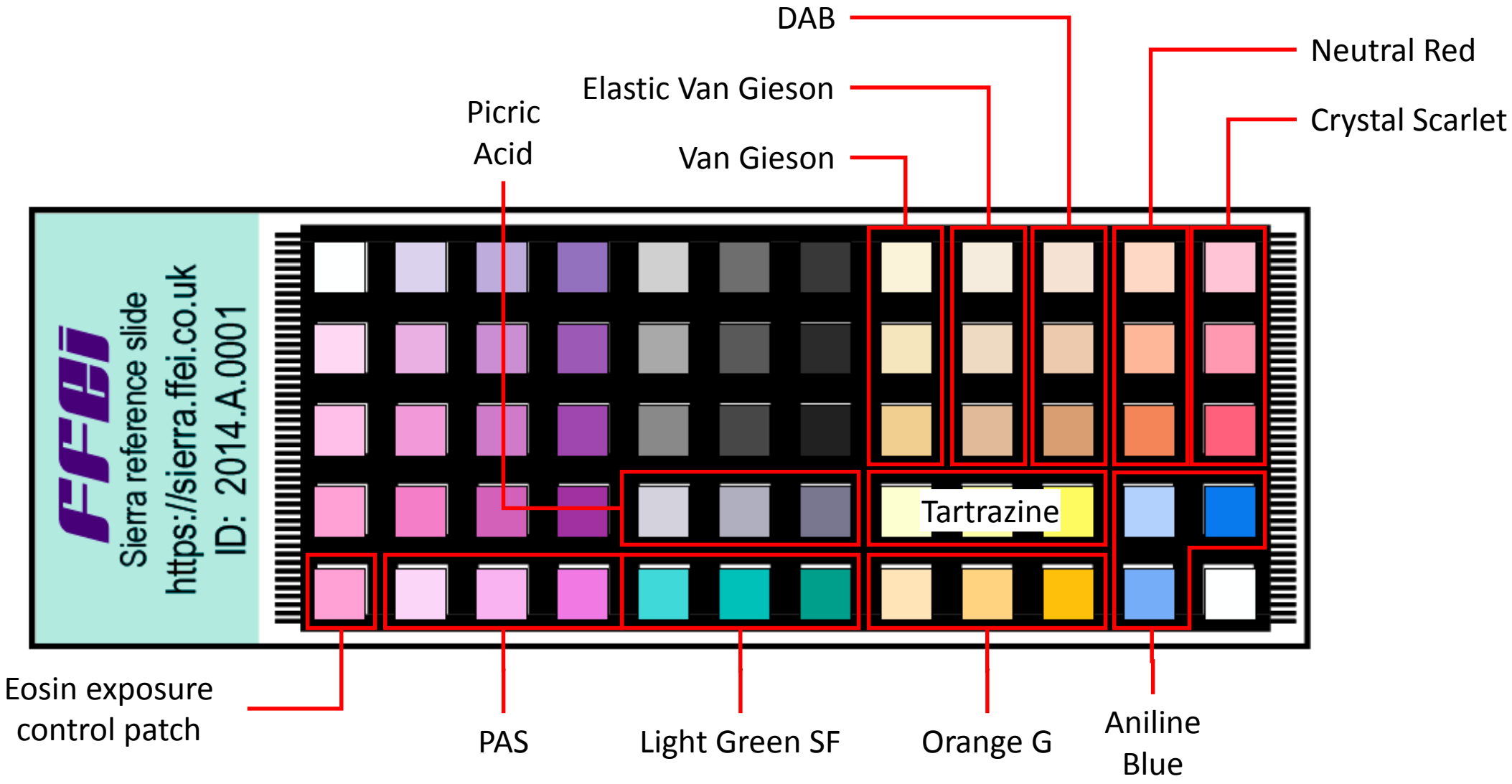


Microscope slide is illuminated by the display back light

Viewing conditions for the microscope slide and slide image are identical

Based on a method developed and promoted by Yukako Yagi and Pinky Bautista

Calibration methods: Sierra calibration slide

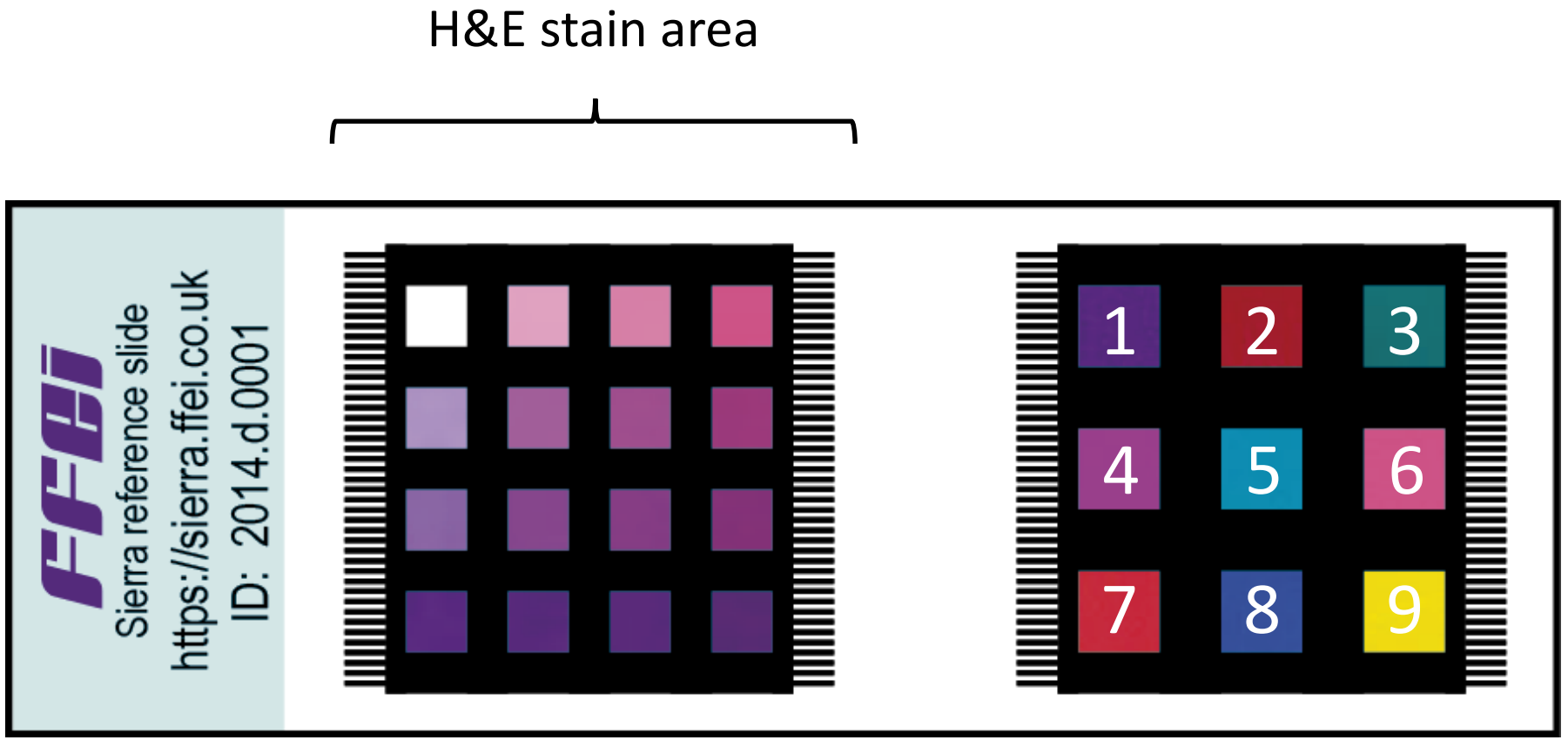


Review of calibration methods

- Target based on photographic film
  - Method is currently available but there may be problems with metamerism
  - Using a film target is good if film is later to be scanned
- Calibration model using sensor sensitivities and known spectra of stained tissue
- Dichroic filter chart and known spectra of stained tissue
- Visual assessment
  - Approximate method but is easy to use
- Sierra calibration slide using pathology stains
  - No progress on manufacturing this slide

Sierra calibration assessment

Sierra calibration assessment slide from FFEI

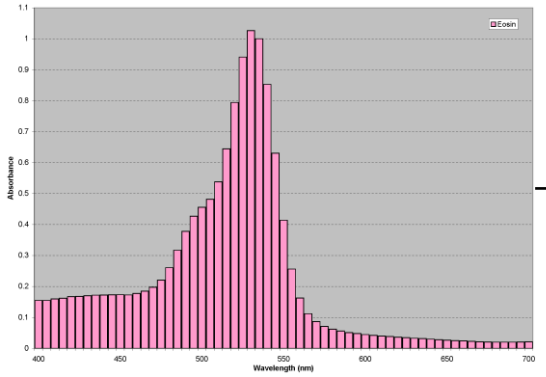


1. Haematoxylin
2. Neutral Red
3. Light Green FS
4. PAS
5. Methyl Green
6. Eosin
7. Ponceau Fuchsin
8. Aniline Blue
9. Tartrazine

Slide uses a biopolymer which can be stained using standard pathology stains

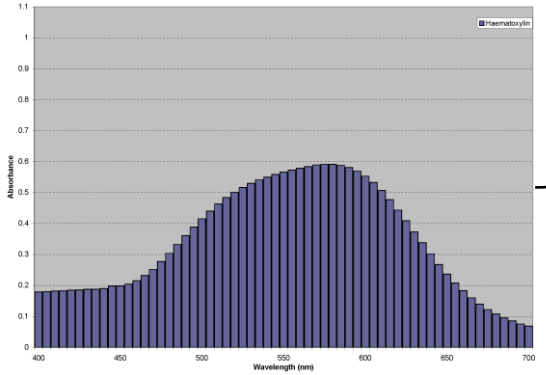
Behaviour of stains
(example – other stains operate similarly)

Eosin



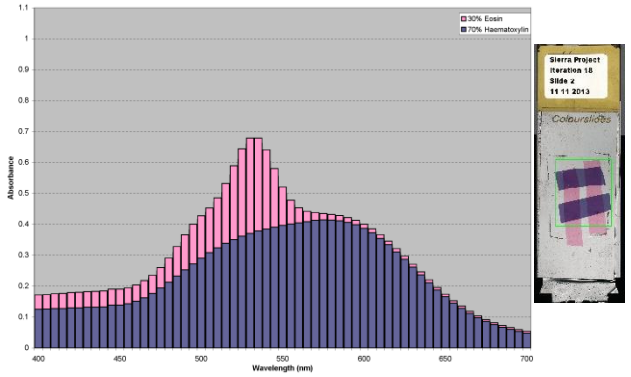
30%

70%



Haematoxylin

30% Eosin + 70% Haematoxylin



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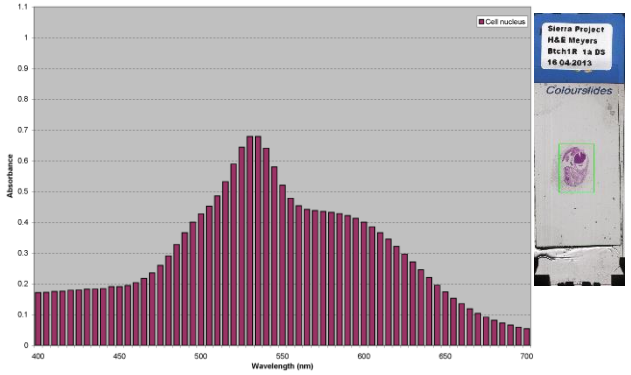
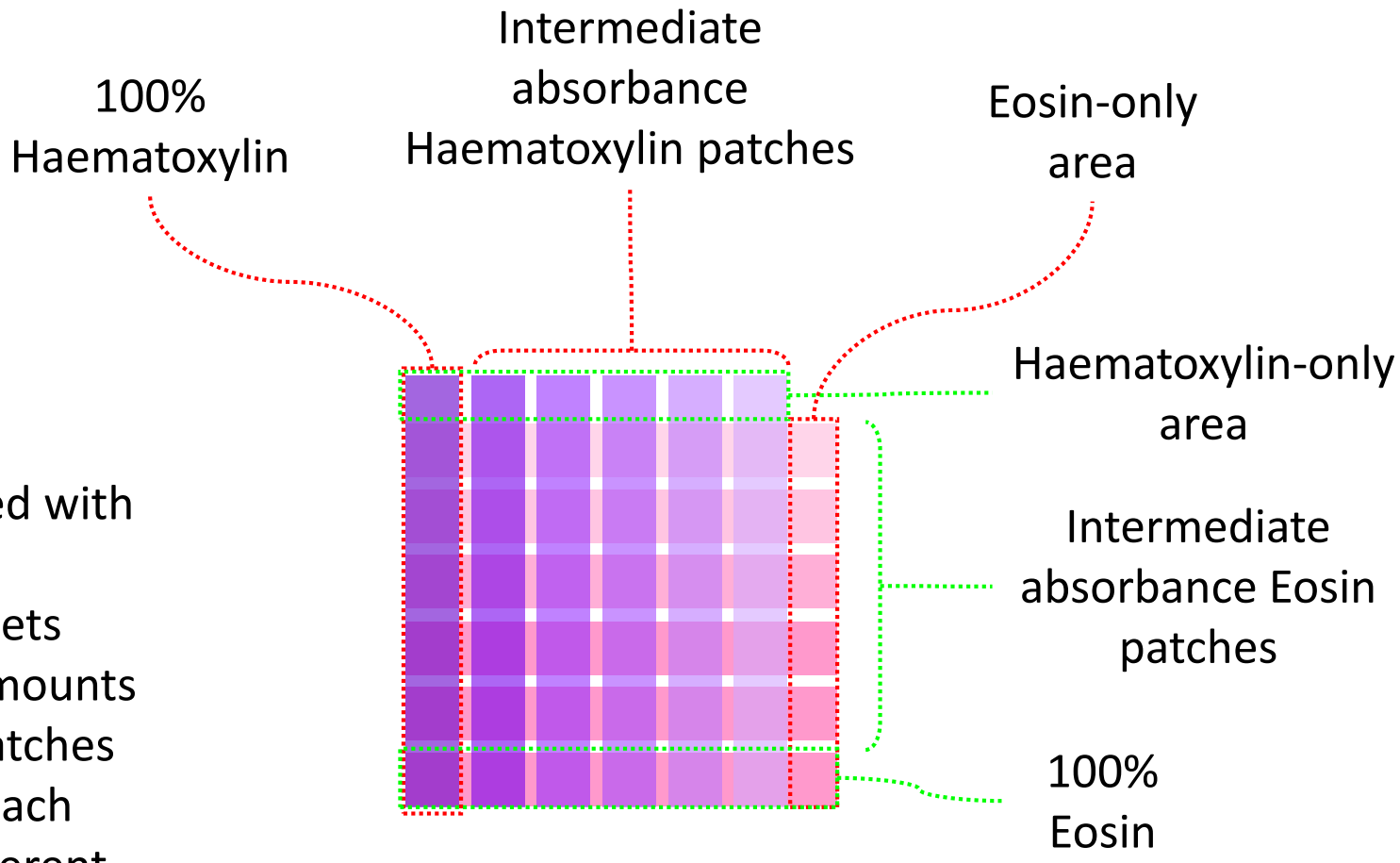


Example colour spectrum is simple linear addition of 30% Eosin and 70% Haematoxylin

H&E stains combinations



Requires N sheets stained with different amounts of Haematoxylin and N sheets stained with different amounts of Eosin to produce N patches with different levels of each single stain and NxN different stain combinations

Stained biopolymer compared to stained tissue

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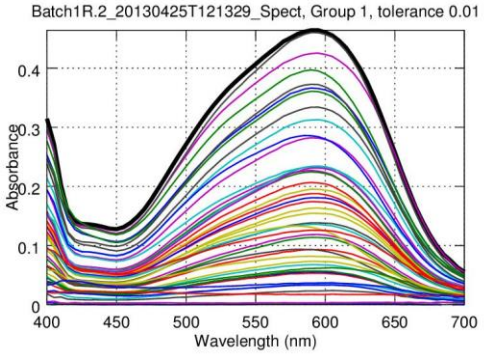
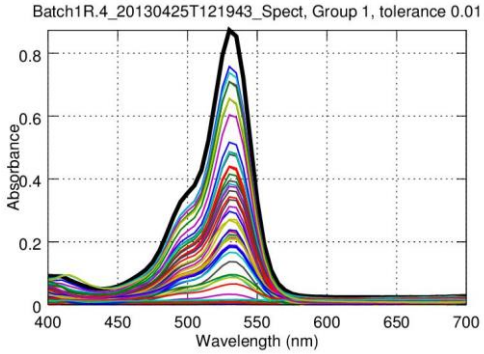
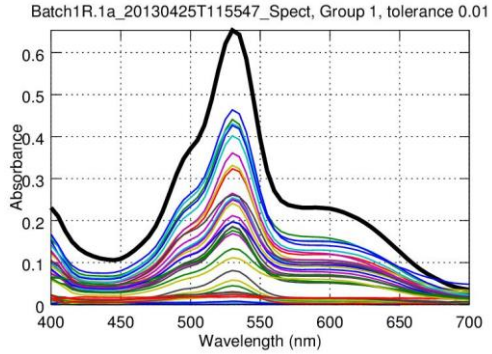
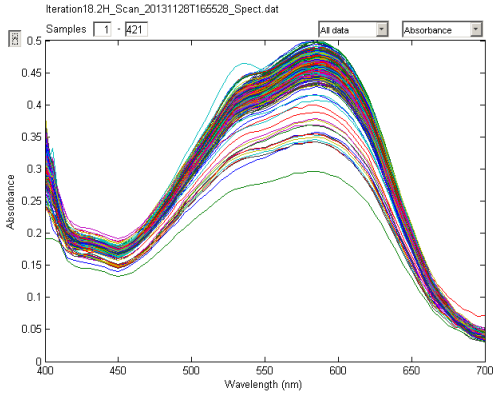
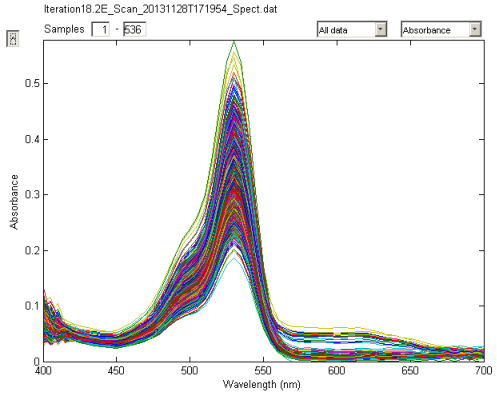
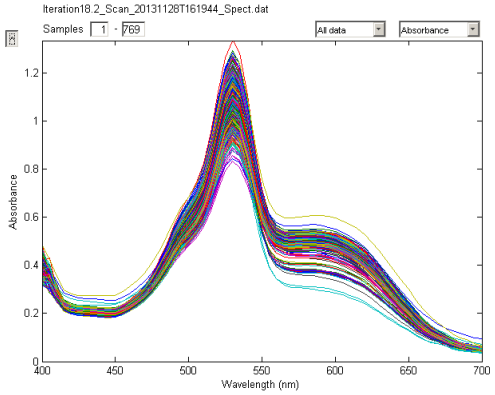
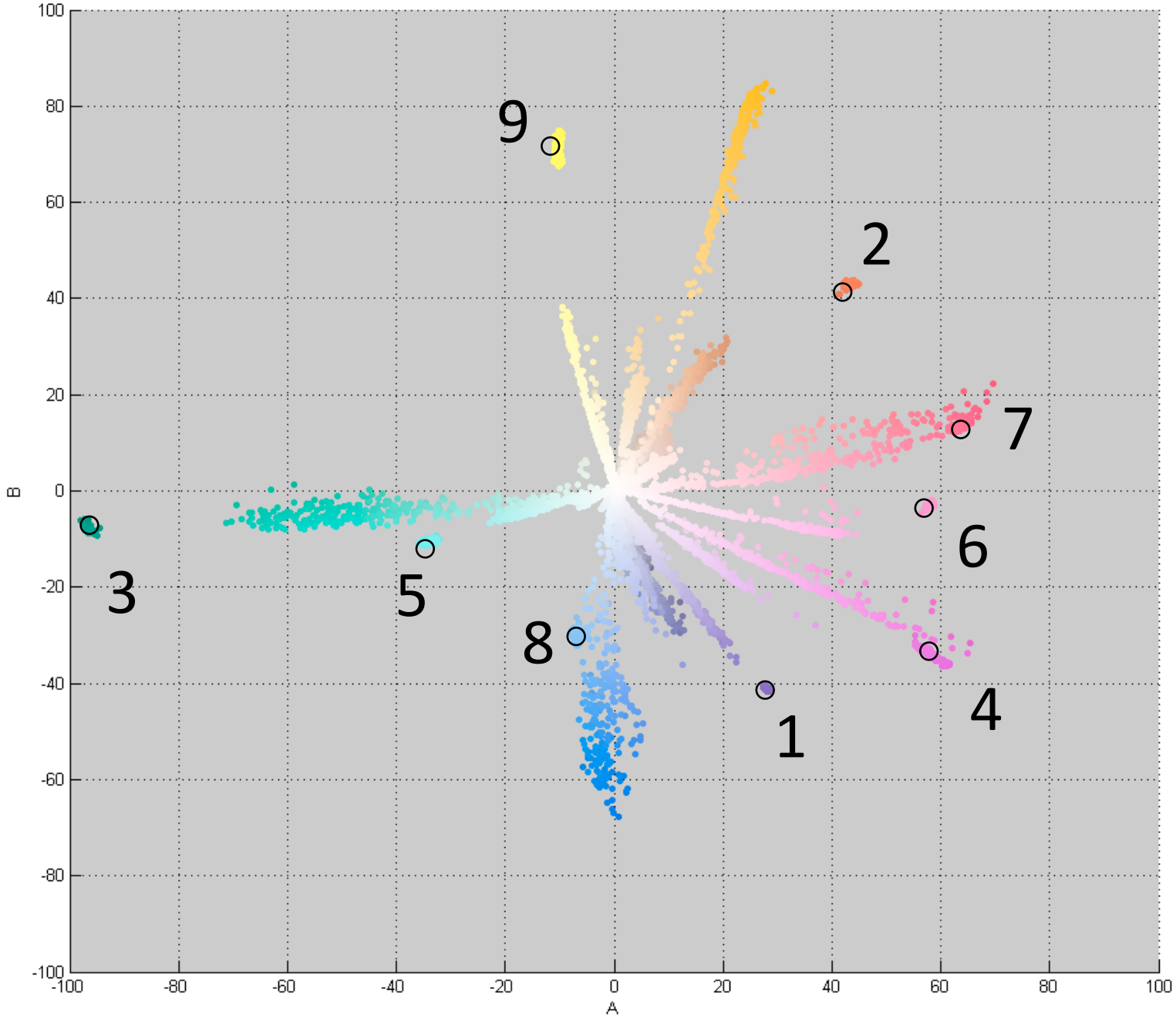
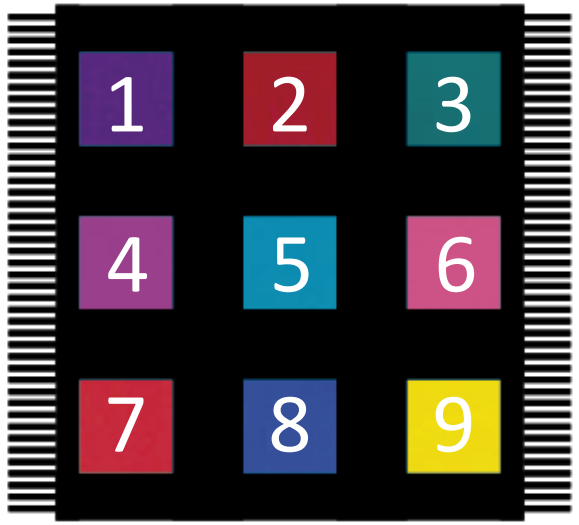
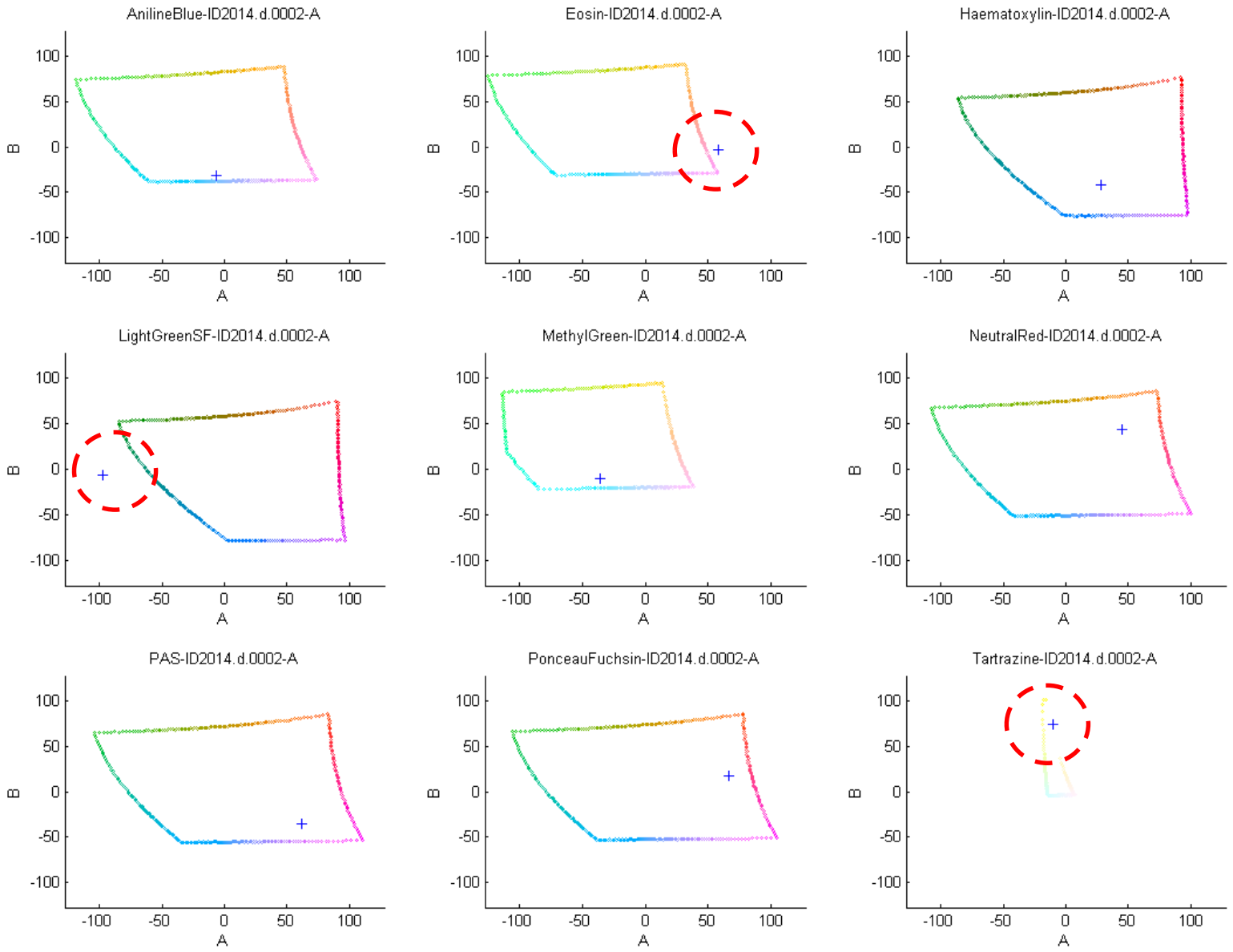
	Haematoxylin	Eosin	H&E stained
Stained tissue measurements			
Stained biopolymer measurements			





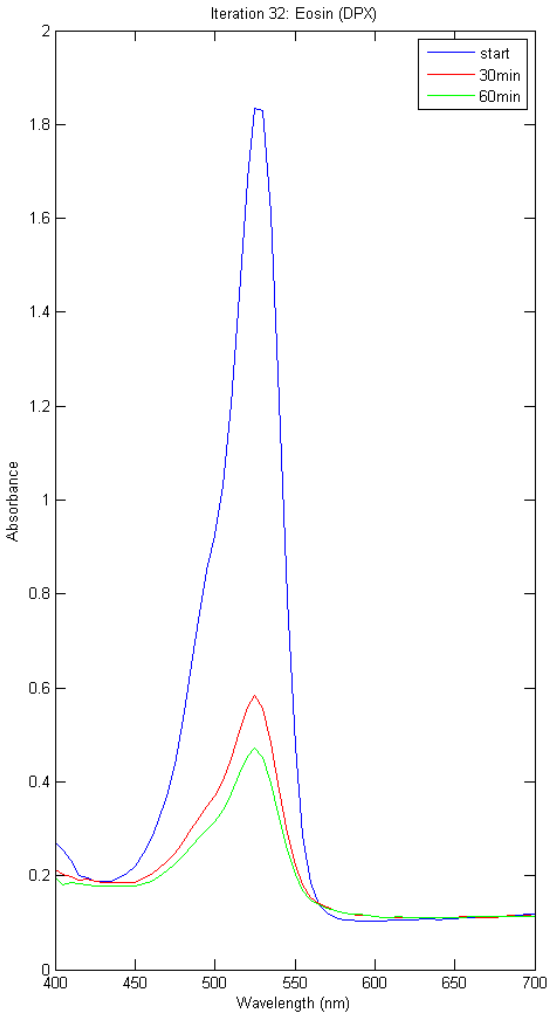
Plot shows the colours found on a selection of stained tissue slides in relation to the colours of the nine patches of the reference slide

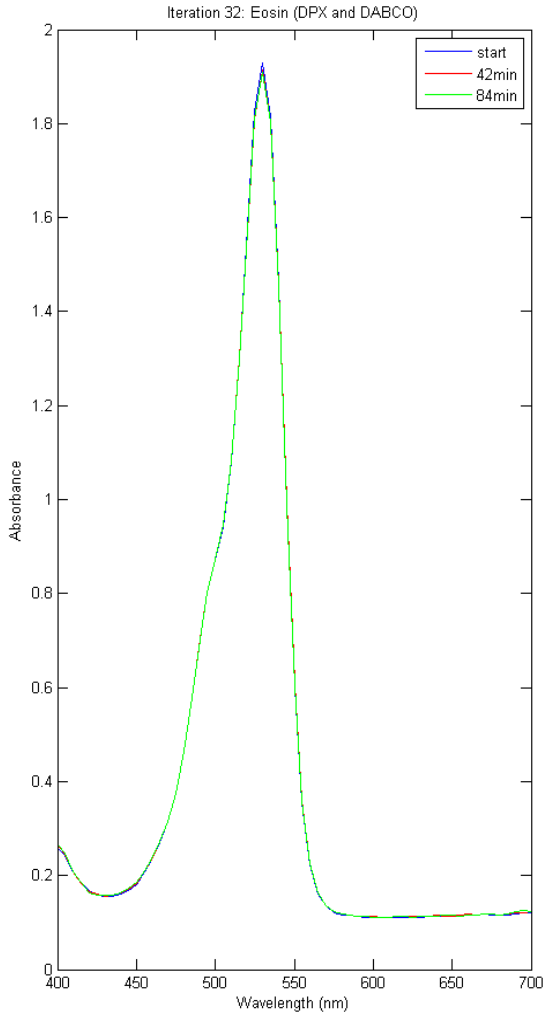


Comparison with typical display colour gamut AdobeRGB+

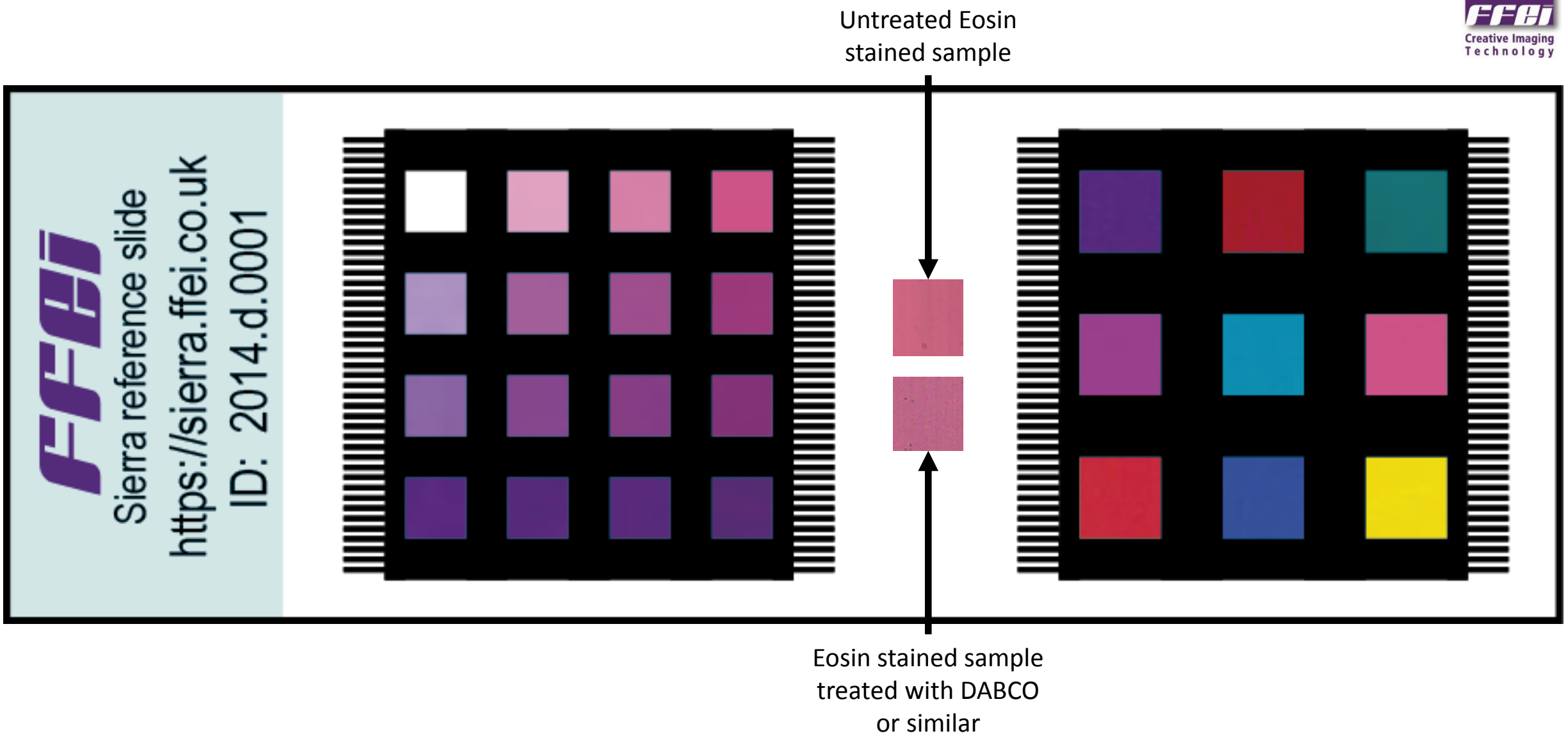
Eosin stabilisation

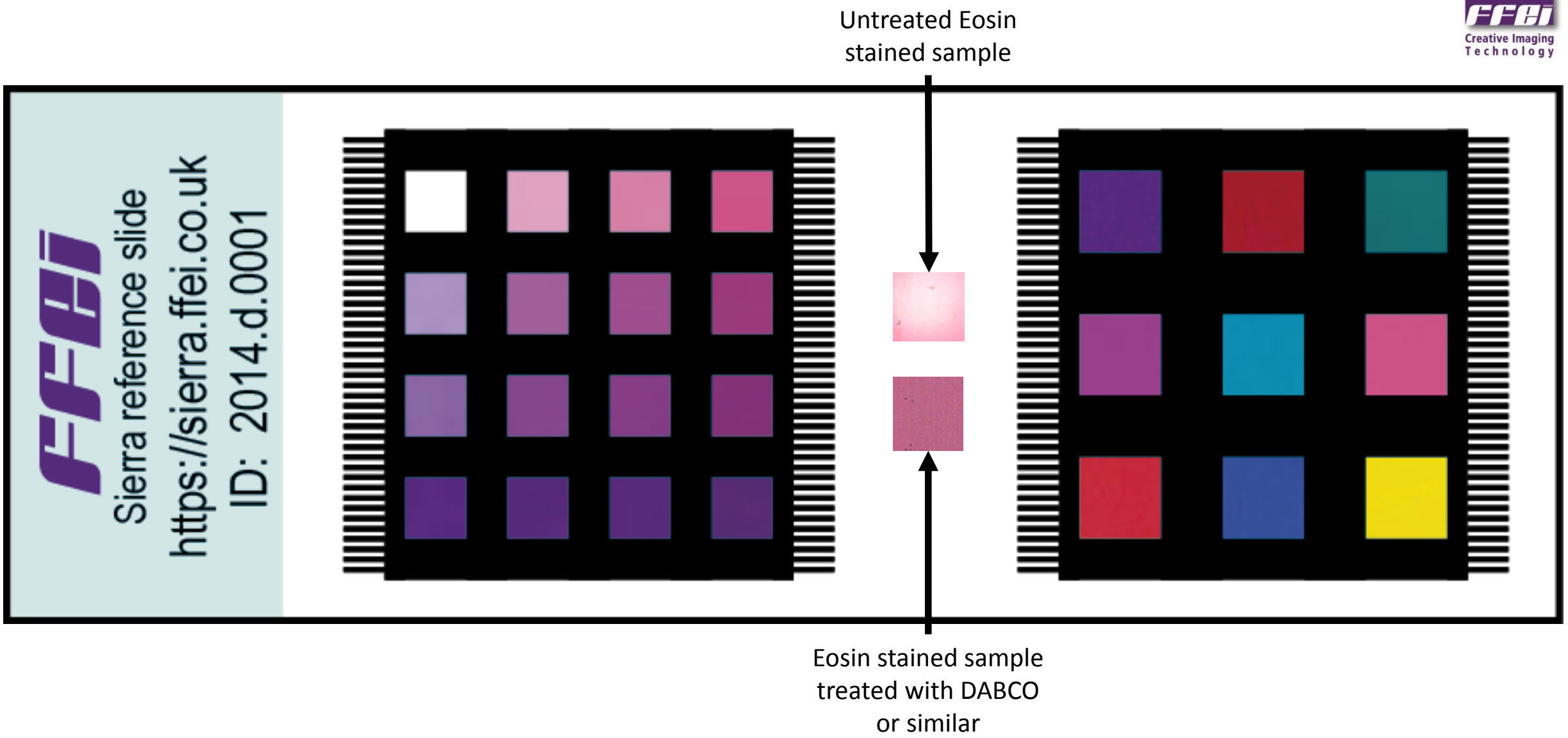
Untreated Eosin
absorbance has dropped to 1/3 of its initial value after 30 minutes exposure to high intensity light source



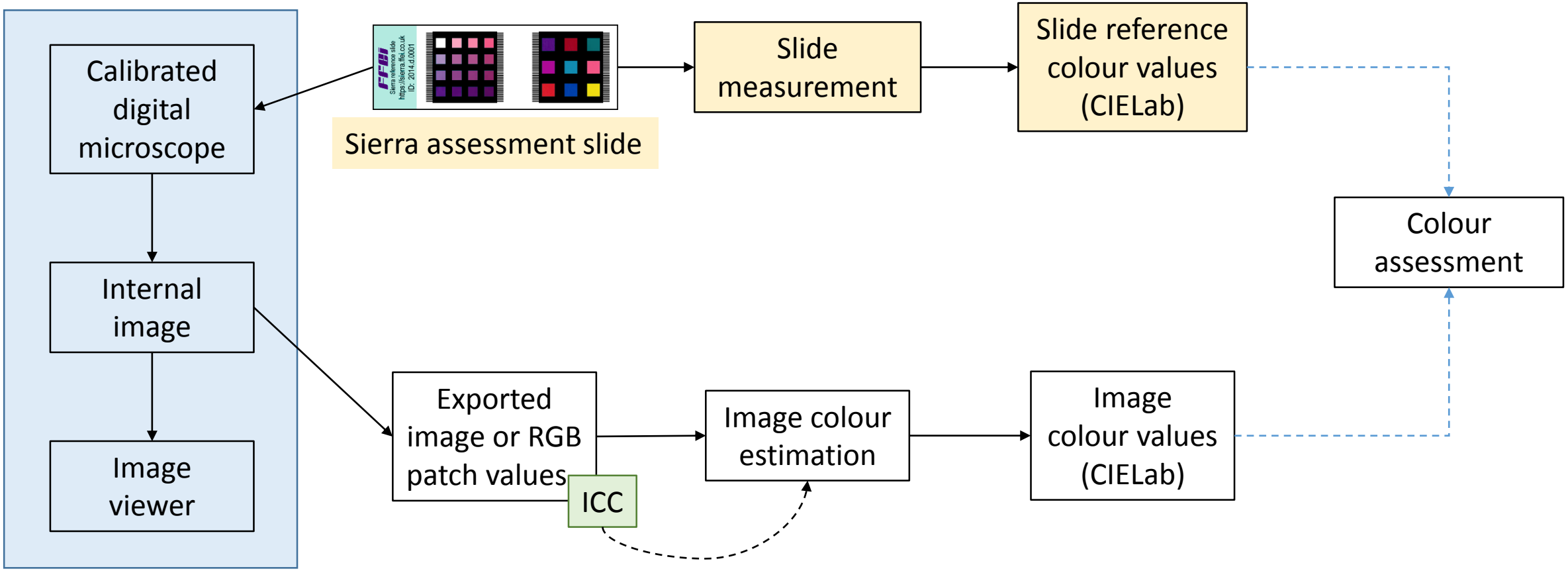


Eosin treated with DABCO
no change in absorbance after continuous exposure to the same high intensity light source for 84 minutes


Untreated Eosin
stained sample
FFEI
Sierra reference slide
https://sierra.ffei.co.uk
ID: 2014.d.0001
Eosin stained sample
treated with DABCO
or similar

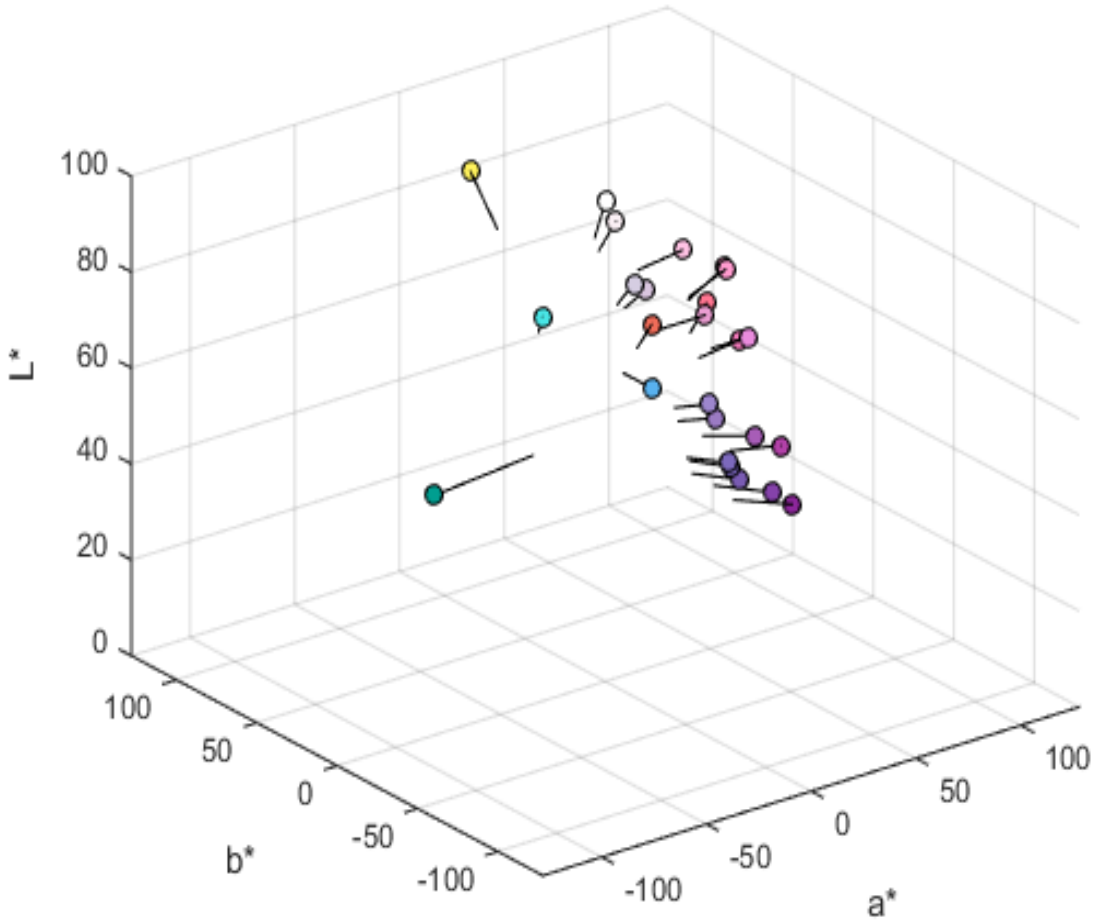

Untreated Eosin
stained sample
FFEI
Sierra reference slide
https://sierra.ffei.co.uk
ID: 2014.d.0001
Eosin stained sample
treated with DABCO
or similar

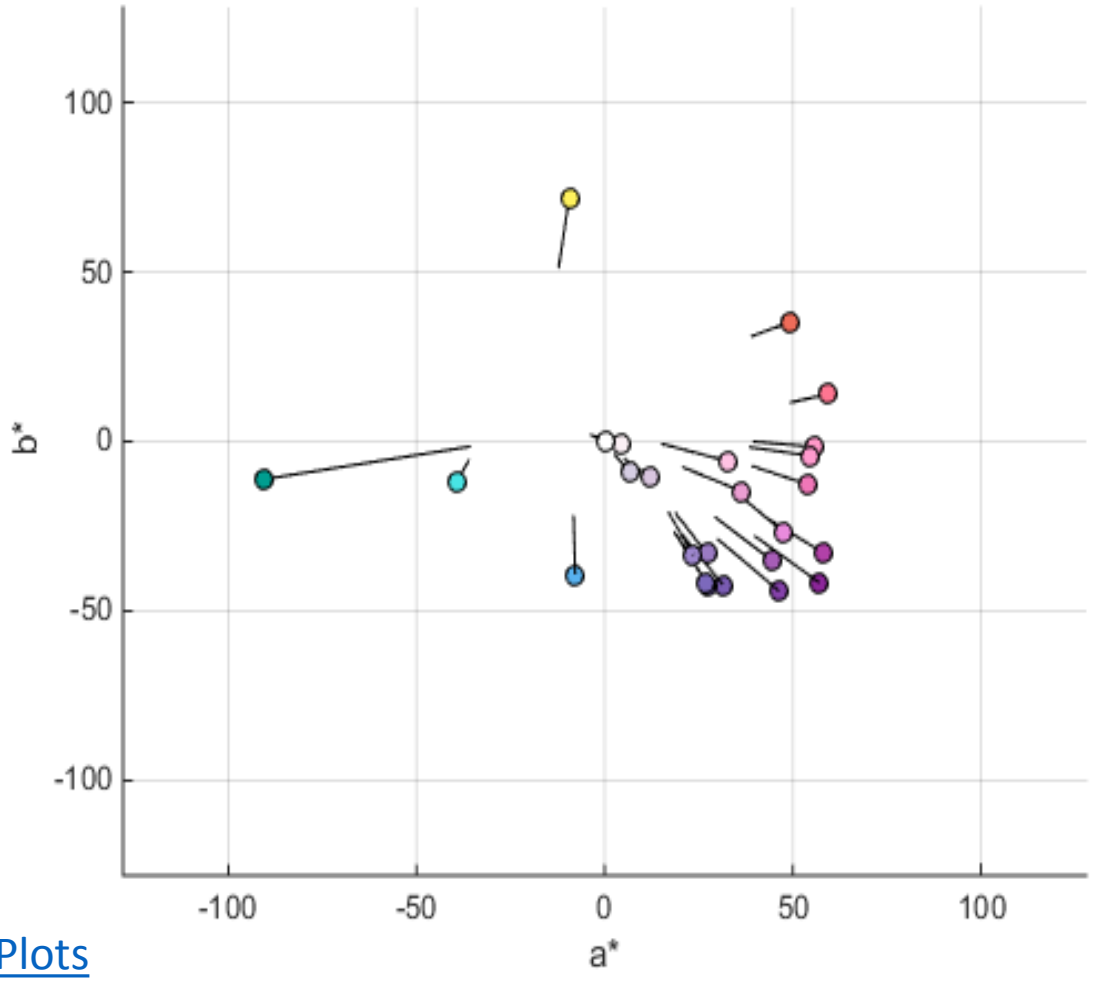
Assessment method



Analysis: plot of Lab values

Lines show difference between Reference Lab (marked with circle) and Image Lab values





Sierra Colour Plots

Sierra calibration assessment

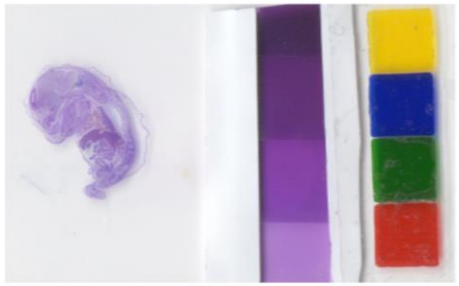
- Sierra round-robin assessment shows significant variation between whole slide imaging systems
  - A total of 9 systems were tested
- What should be used for reference illuminant?
  - D50: ICC Profiles use D50 for Profile Connection Space
  - Actual illuminant used – requires chromatic adaptation
- Reference white may not be the lightest colour
  - In most cases the reference white assumed by the viewer is lighter than the white of the clear patch
- What should be the colour objective?
  - Relative colorimetric – some colours may be out of gamut for sRGB displays
  - Pathologist preference may not be relative colorimetric

Staining assessment : Dr David Brettle (Leeds)

Creative Imaging Technology

Point of use QA concepts

An embedded environment in the image that is responsive to all the processes applied to the image, from acquisition to display, and allows assessment of image quality at any time or point in the image life. For use on all mission critical images, x-ray, forensics etc.



Digital Pathology

X-ray

Possible solution?

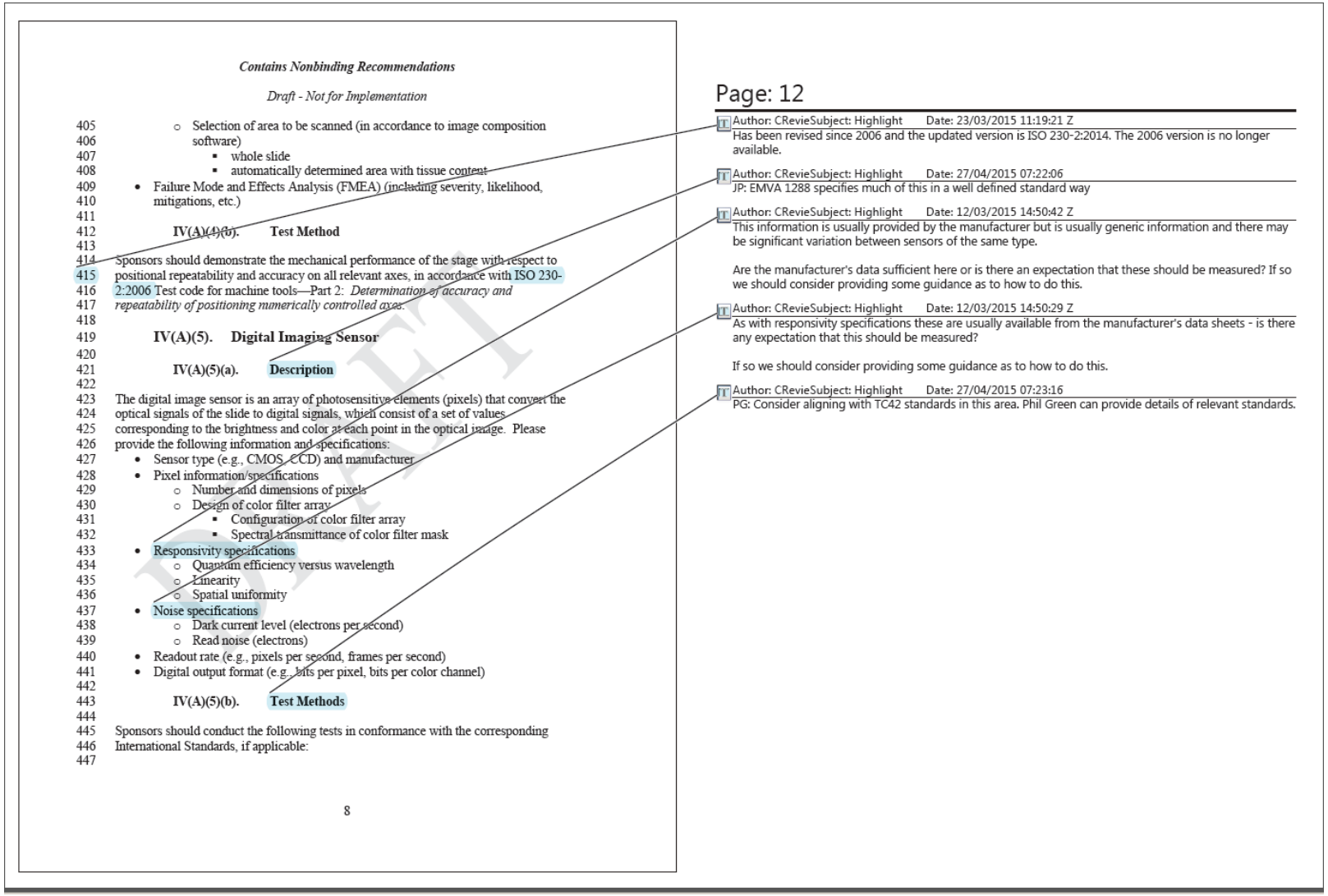
Color Reference Patch Substrate Patch Substrate Patch: Stained

Leeds Cancer Centre

FDA draft guidance review and comment

ICC Comments on FDA draft guidance

Technical Performance Assessment of Digital Pathology Whole Slide Imaging Devices



Contains Nonbinding Recommendations

Draft - Not for Implementation

- Selection of area to be scanned (in accordance to image composition software)
  - whole slide
  - automatically determined area with tissue content
- Failure Mode and Effects Analysis (FMEA) (including severity, likelihood, mitigations, etc.)

IV(A)(4)(b). Test Method

Sponsors should demonstrate the mechanical performance of the stage with respect to positional repeatability and accuracy on all relevant axes, in accordance with ISO 230-2:2006 Test code for machine tools—Part 2: *Determination of accuracy and repeatability of positioning numerically controlled axes.*

IV(A)(5). Digital Imaging Sensor

IV(A)(5)(a). Description

The digital image sensor is an array of photosensitive elements (pixels) that convert the optical signals of the slide to digital signals, which consist of a set of values corresponding to the brightness and color at each point in the optical image. Please provide the following information and specifications:

- Sensor type (e.g., CMOS, CCD) and manufacturer
- Pixel information/specifications
  - Number and dimensions of pixels
  - Design of color filter array
    - Configuration of color filter array
    - Spectral transmittance of color filter mask
- Responsivity specifications
  - Quantum efficiency versus wavelength
  - Linearity
  - Spatial uniformity
- Noise specifications
  - Dark current level (electrons per second)
  - Read noise (electrons)
- Readout rate (e.g., pixels per second, frames per second)
- Digital output format (e.g., bits per pixel, bits per color channel)

IV(A)(5)(b). Test Methods

Sponsors should conduct the following tests in conformance with the corresponding International Standards, if applicable:

8

Page: 12

Author: CRevieSubject: Highlight Date: 23/03/2015 11:19:21 Z
Has been revised since 2006 and the updated version is ISO 230-2:2014. The 2006 version is no longer available.

Author: CRevieSubject: Highlight Date: 27/04/2015 07:22:06
JP: EMVA 1288 specifies much of this in a well defined standard way

Author: CRevieSubject: Highlight Date: 12/03/2015 14:50:42 Z
This information is usually provided by the manufacturer but is usually generic information and there may be significant variation between sensors of the same type.

Are the manufacturer's data sufficient here or is there an expectation that these should be measured? If so we should consider providing some guidance as to how to do this.

Author: CRevieSubject: Highlight Date: 12/03/2015 14:50:29 Z
As with responsivity specifications these are usually available from the manufacturer's data sheets - is there any expectation that this should be measured?

If so we should consider providing some guidance as to how to do this.

Author: CRevieSubject: Highlight Date: 27/04/2015 07:23:16
PG: Consider aligning with TC42 standards in this area. Phil Green can provide details of relevant standards.

ICC Comments reviewed during April
Submitted on 8th May 2015
Tracking Number: 1jz-8iqb-lgnt

Total of 14 sets of comments received by the FDA

Next steps – some initial ideas

- Update ***Digital microscope test materials and test methods*** document
- Create ICC documents to complement FDA guidance for whole slide imaging
- Second round-robin using Sierra slide with objective of recommending acceptable colour tolerances
- Perform end-to-end testing including display calibration

- Please suggest additional work for ICC MIWG

LED colour generator and its application

Shizuoka university

Hitoshi Urabe

Yoshifumi Shimodaira

Today's talk

1. What is LED colour generator?

2. Content of ISO/TS 17321-4

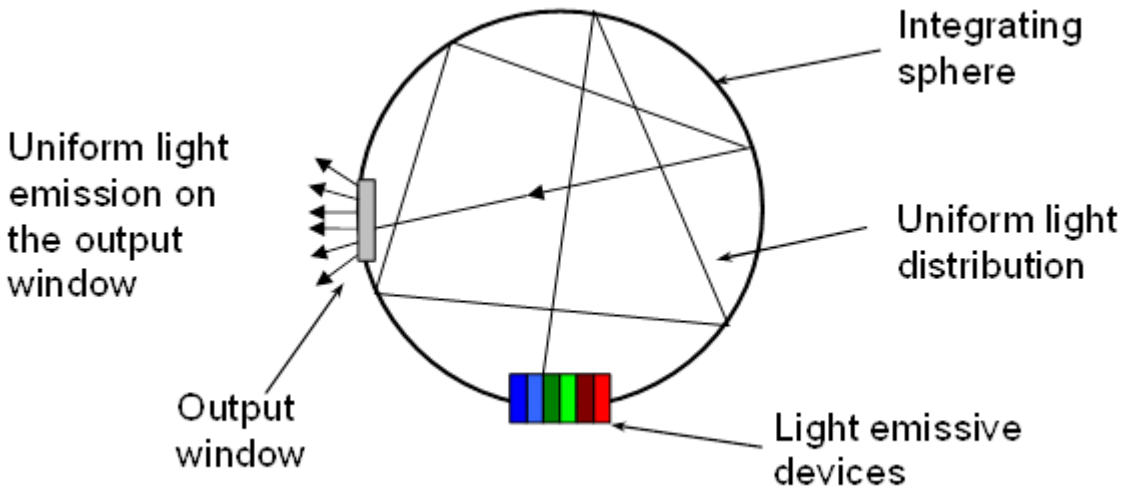
3. Error analysis

4. Optimization procedure to obtain aimed spectral distribution

5. Several applications

1. What is LED colour generator?

Principle of the light emission system



LED colour generator -- 1 --

(a)

(b)

Figures above are Prototype 2.

(a) Operating under a mode of touching a colour patch.

(b) Operating under a mode of touching intensity bars.

14 LEDs, 8-bit D/A converter

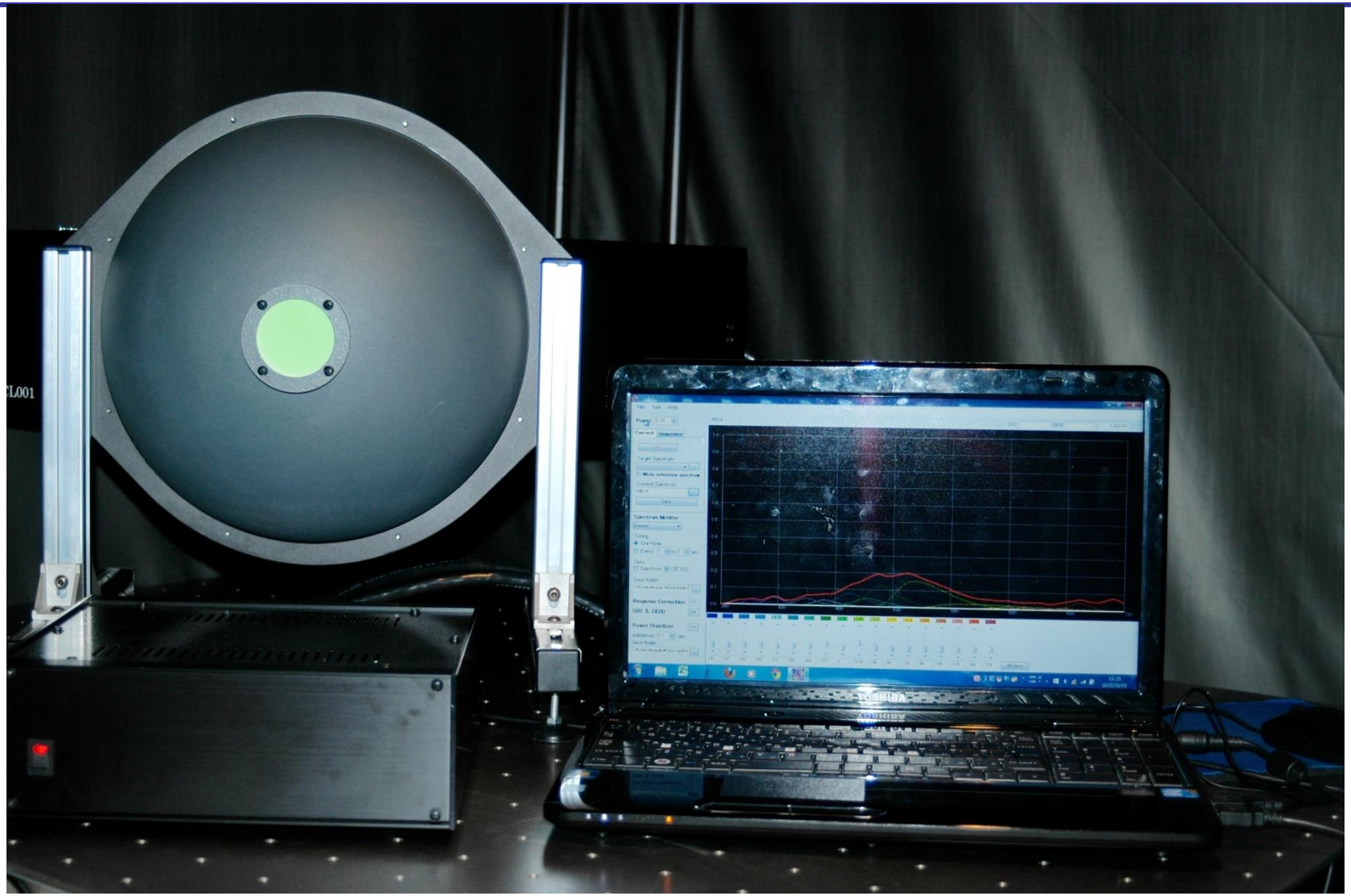
Many advantages below.

An arbitrary smooth spectral power distribution similar to colour targets under a light source can be generated.

Many colour metamers can be generated easily.

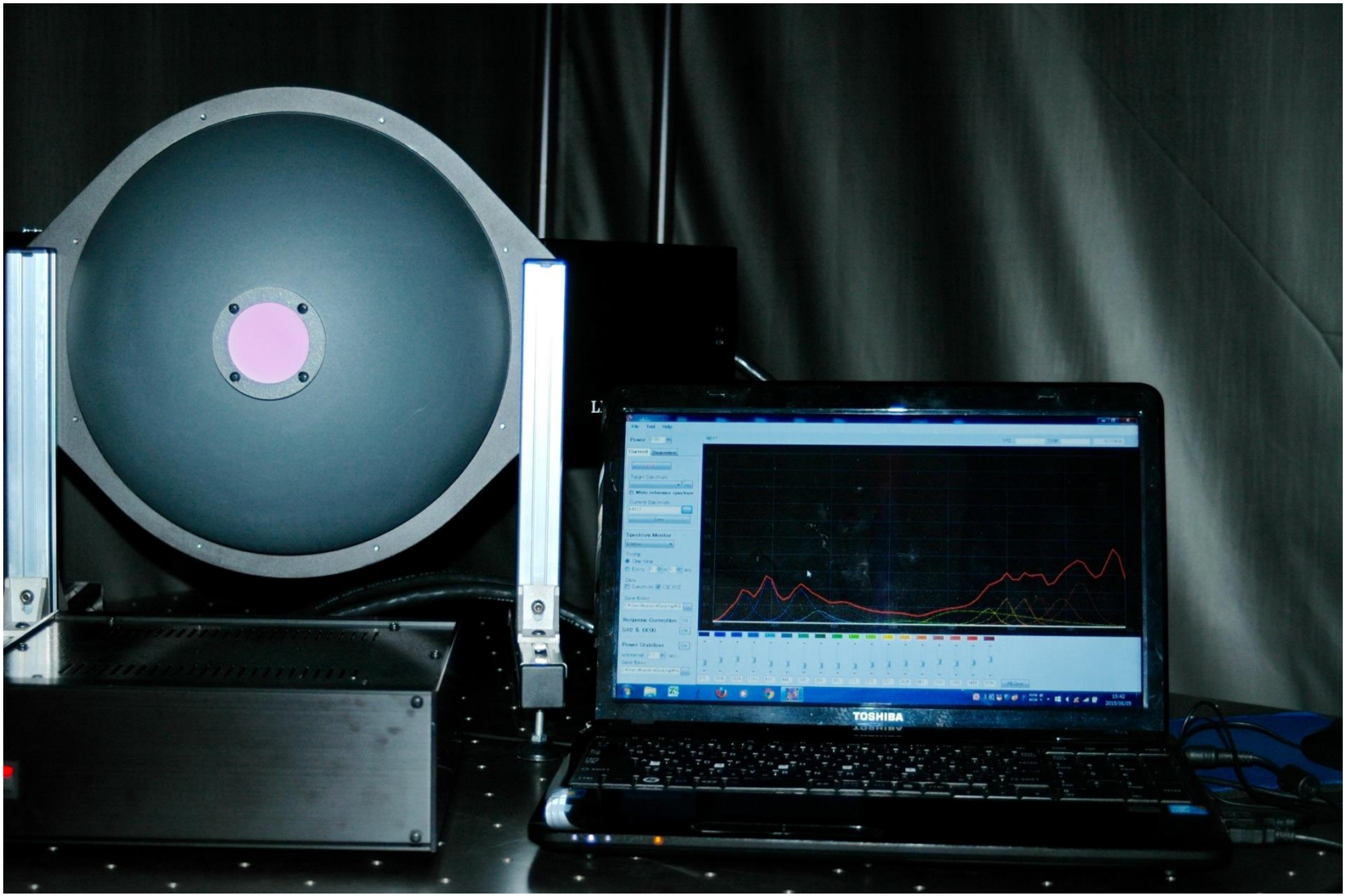
Automatical PC-control to adjust LED intensity

Proto3 ： Macbeth #14 Green

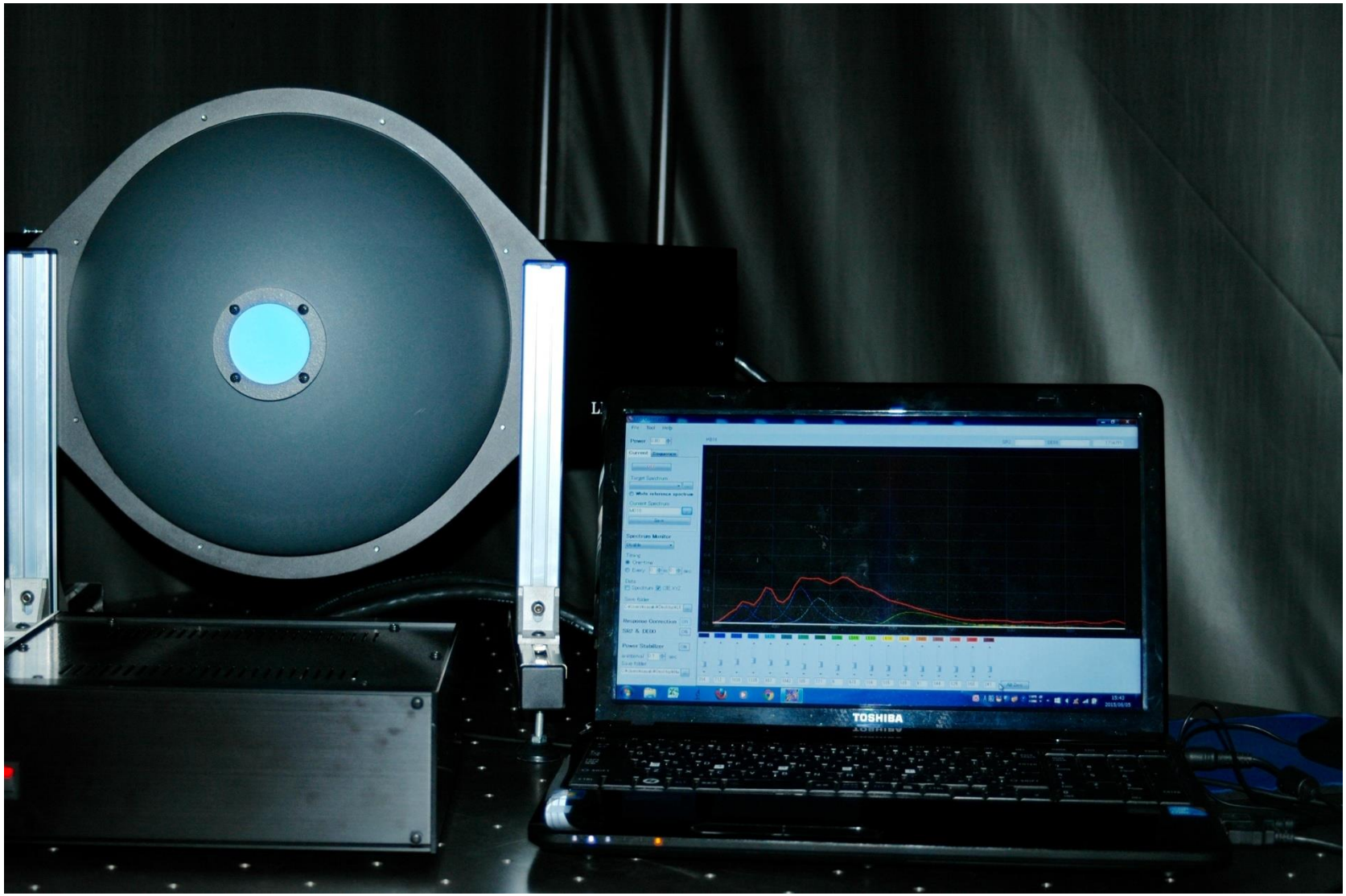


30 cm in diameter, 400 cd/m2, 18 LEDs, 12-bit D/A C

Proto3 ： Macbeth #17 Magenta



Proto3 ： Macbeth #18 Cyan



2. Content of ISO/TS 17321-4

Graphic technology and Photography – Colour characterization of digital still camera (DSCs) – Part 4: Programmable light emission system

ISO/TS 17321-4 will be published next year.

Main body

- Hardware requirements
- Evaluation method for spectral distribution

Annex

- Spectral power distribution optimization procedure
- Evaluation method for light source

Hardware requirements

Operating condition : Temperature: 18 °C to 28 °C

Relative humidity: 15 % to 80 %

Wavelength : 380 nm - 730 nm

Minimum luminance : 40 cd/m^2

Output window : at least 50mm in diameter

Uniformity : ΔY shall be within ± 2 %. 8 points

Angular characteristic :ΔY shall be within ± 2 %.

5 degree of arc.

Time stability :

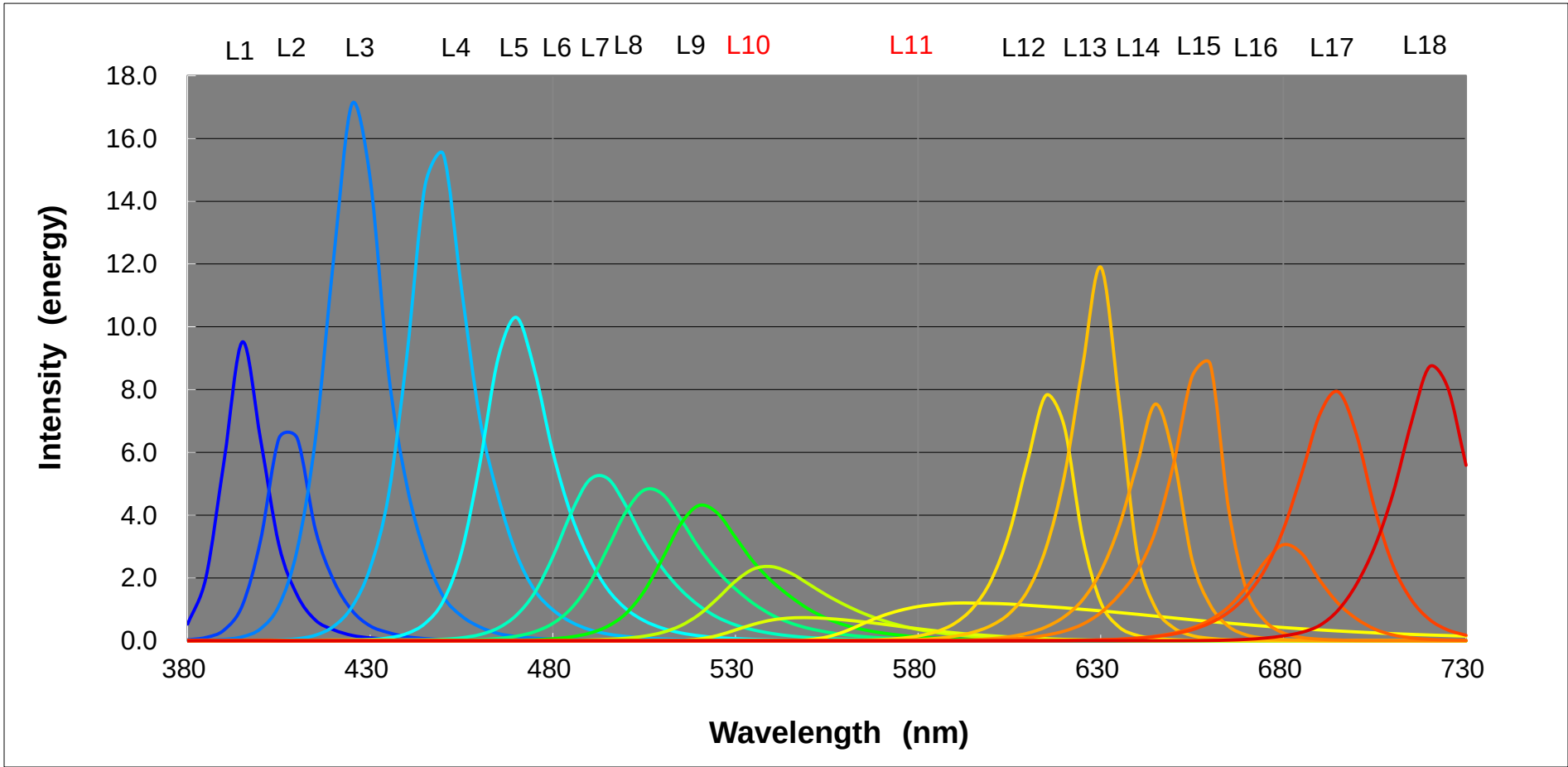
Reproducibility (SD) ΔE_{00} <= 0,3

Maximum ΔE_{00} <= 0,6

LED selection

No good green LED in the market.

Added fluorescent type LEDs with band pass filter such as L10 and L11.

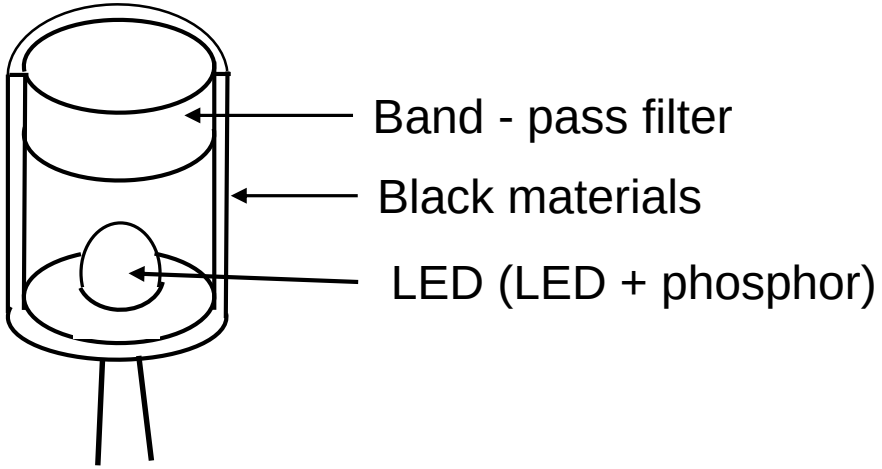


LEDs selection –

Light source types used in the prototype target

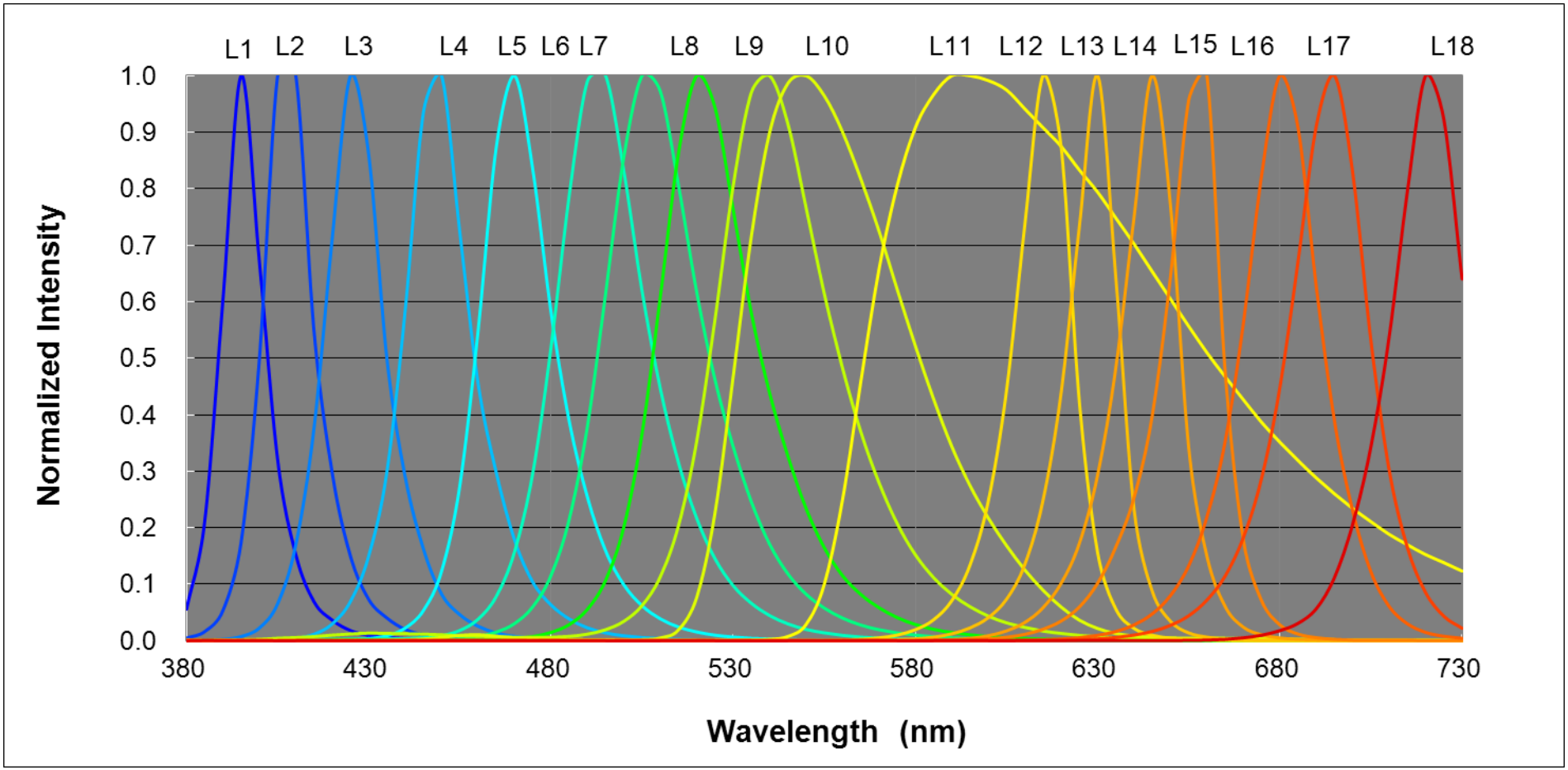
L10 and L11 : LED (LED + phosphor) + wide band filter

Other light sources : Typical LED structures



Sample structure of L10, L11 light source.

Prototype 3 : Normalized spectra of 18 LEDs



Evaluation method for light source -- 1 --

SR2L is the mean of the squares of the difference between two light source spectral power distributions

$$S_{R2L} = \frac{\sum_{i=1}^{N} \left(\left(L_{ri} - P E_{gi} \right) / Y_L \right)^2}{N} \qquad Y'_L = \sum_{i=1}^{N} V_{ri} L'_{ri} \qquad \sum_{i=1}^{N} V_{ri} = 1$$

L_{ri} is the reference light source spectrum of the *i*-th wavelength,

E_{gi} is the spectrum of the *i*-th wavelength generated by the light emission system

P is the scaling coefficient to adjust energy power level

V_{ri} is the normalized-response of the *i*-th wavelength derived from the luminosity function,

Y_L is the normalization factor to remove light source dependence,

Normalized YLs are following.

E	D55	D65	A	F8 high Ra type	F10 three wavelength type
1.000	0.894	0.920	1.012	0.787	0.631

Evaluation method for light source -- 2 --

How to calculate Ps?

1) Measure the (absolute) spectral power distribution of each LED at its maximum intensity.

2) Using the optimization procedure described in Annex B, optimize S_{R2L} value. This procedure calculates intensity values set(A) for all LED

3) Ps = MAX(an intensity values of set(A))

4) In order to obtain feasible spectrum distribution, intensity values set(B) = intensity values set(A) / Ps

← feasible for the system because of 0 – 1 intensity value for all LEDs

5) Multiply each LED measured-spectral power distribution by the corresponding LED intensity value(B) obtained and sum all of spectral power distributions to obtain E_{gi}.

Ps = 92.92 for D55, 96.11 for D65 and 84.90 for A (Prototype 3)

Evaluation method for light source -- 3 --

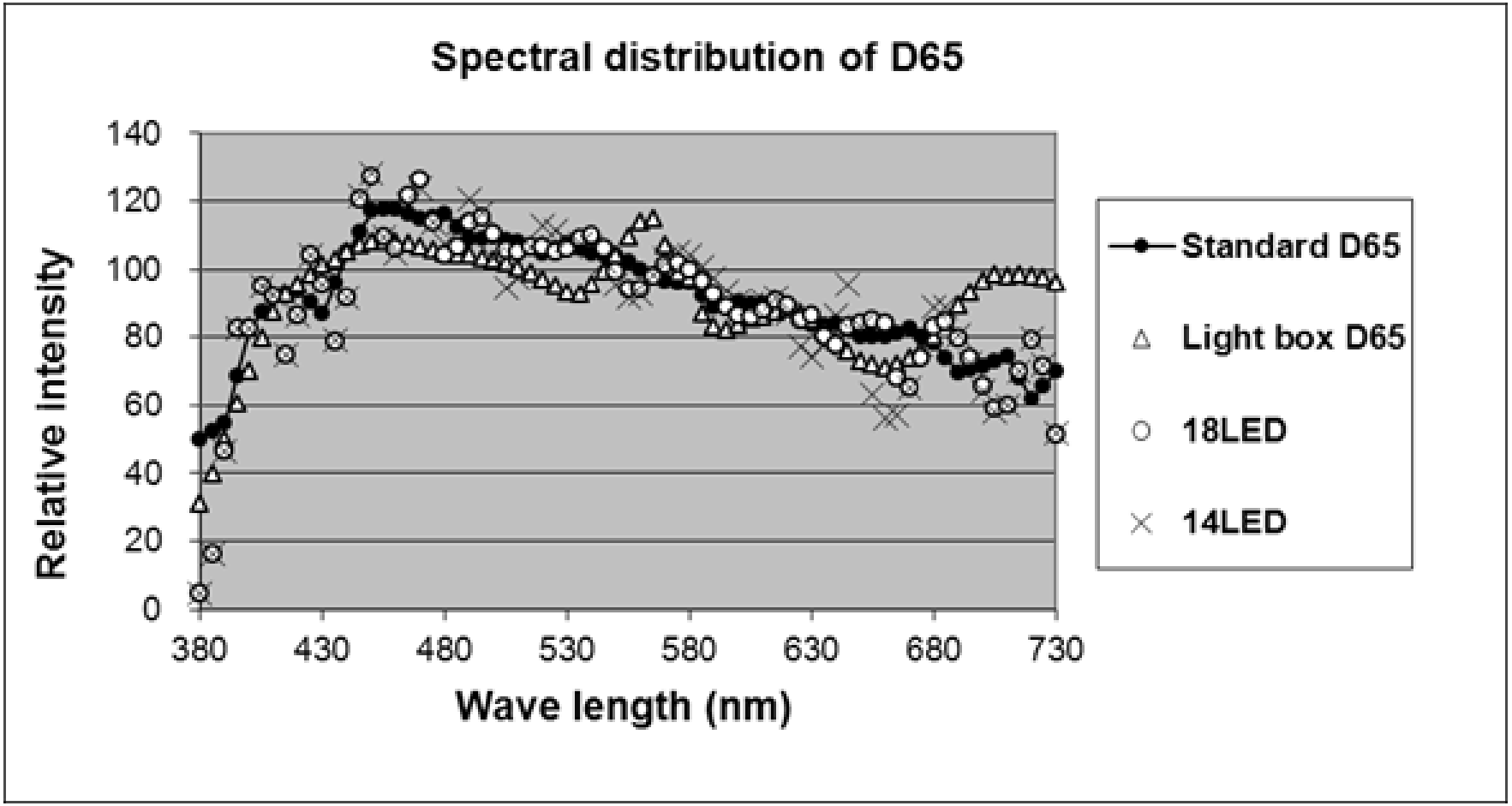
Colour Rendering Index : CIE 13.3:1995

chromatic coordinates (x,y)

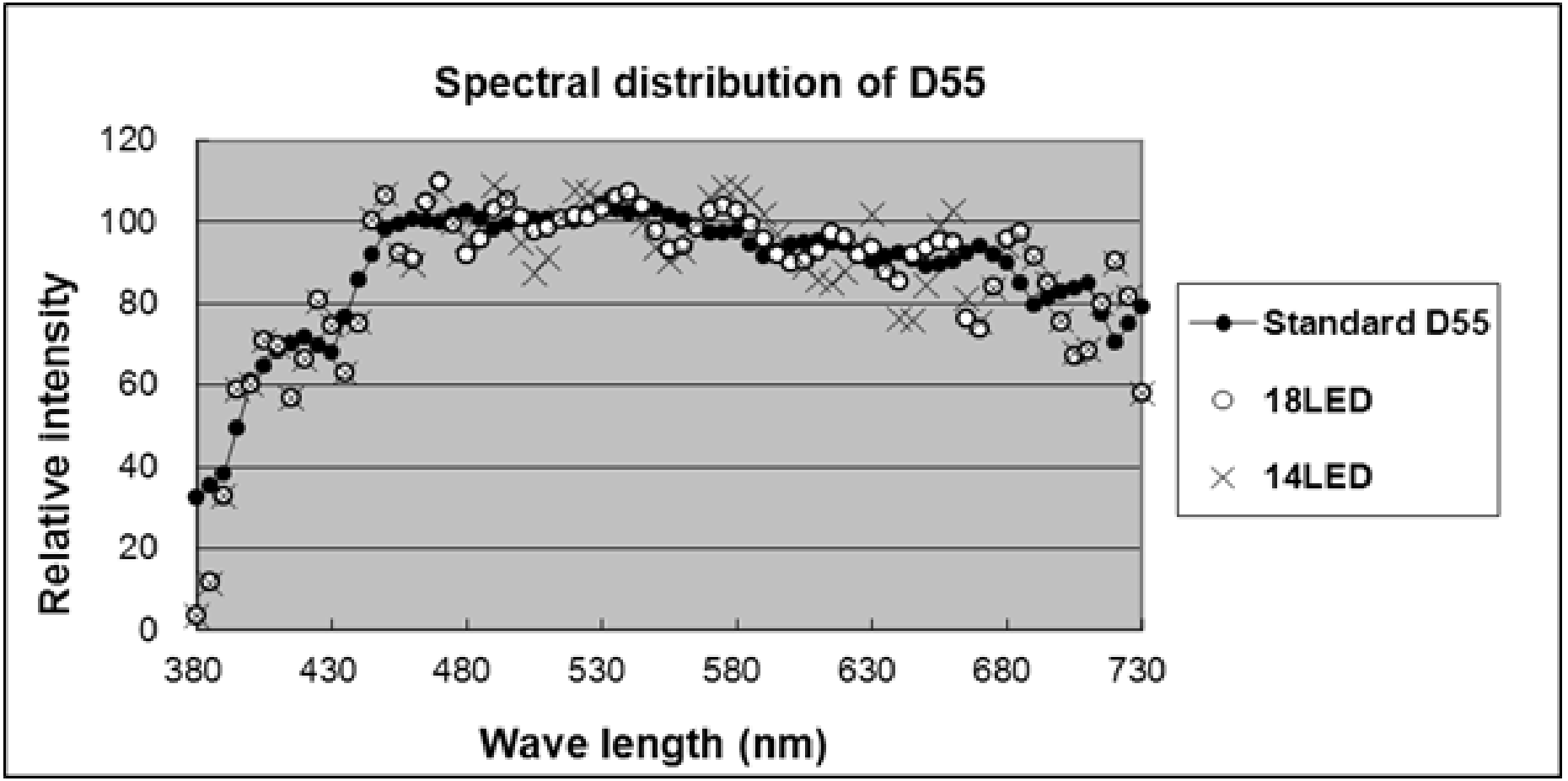
CCT [T_{cp}] : T_{cp} is temperature of the Plankian radiator having the chromaticity nearest the chromaticity associated with the given spectral distribution on a diagram where the (CIE 1931 standard observer based) u', 2/3v' coordinates of the Plankian locus and the test stimulus are depicted. (CIE pub 17-258)

Duv is closest distance from the Plankian locus on the (u', 2/3v') diagram, with + sign for above and – sign for below the Plankian locus. (ANSI C78.377-2008)

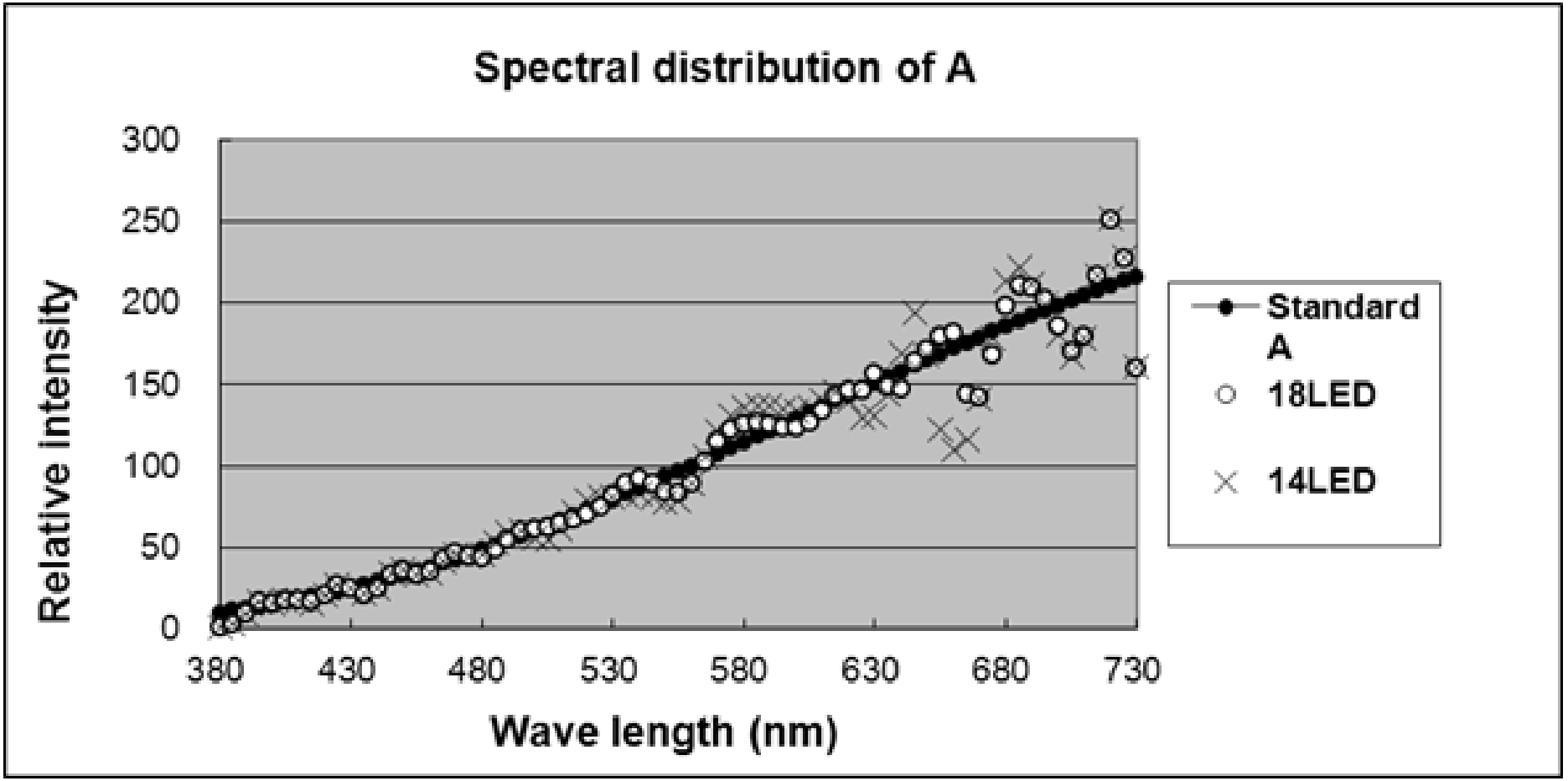
Spectral distribution of 65



Spectral distribution of 55



Spectral distribution of A



Evaluation metrics for light sources

	D65	D65	D65	D55	D55	A	A
Target number (Munsell HV/C)	Light box	18 LEDs	14 LEDs	18 LEDs	14 LEDs	18 LEDs	14 LEDs
S_{R2I}	0,0156	0,0114	0,0150	0,0087	0,0108	0,0168	0,0354
1(7,5R6/4)	96,4	99,3	98,1	99,1	96,5	98,4	93,8
2(5Y6/4)	96,6	99,7	99,3	99,6	98,7	99,4	97,9
3(5GY6/8)	97,3	99,8	98,8	99,6	97,9	98,9	94,6
4(2,5G6/6)	97,4	99,5	98,4	99,3	96,8	98,6	94,2
5(10BG6/4)	96,9	99,5	98,6	99,4	97,3	98,8	95,3
6(5PB6/8)	95,2	99,7	99,2	99,7	98,8	99,7	98,9
7(2,5P6/8)	97,5	99,7	98,1	99,6	97,7	99,2	94,8
8(10P6/8)	98,1	99,3	95,4	99,0	94,9	98,2	88,6
9(4,5R4/13)	95,6	97,5	86,6	97,1	86,8	96,2	76,6
10(5Y8/10)	92,3	99,5	98,7	99,4	98,0	99,5	98,0
11(4,5G5/8)	95,3	99,6	98,6	99,6	97,1	99,1	95,2
12(3PB3/11)	94,3	98,3	99,4	98,2	98,9	96,6	96,2
13(5YR8/4)	95,5	99,4	98,5	99,2	97,1	98,5	94,5
14(5GY4/4)	98,4	99,8	99,3	99,7	98,6	99,2	96,5
Ra=R1-8	96,9	99,5	98,2	93,4	97,3	98,9	94,8
R9-14	95,2	99,0	96,8	98,9	96,1	98,2	92,8
R1-14	96,2	99,3	97,6	99,2	96,8	98,6	93,9
Chromatic coordinates (x, y)	(0,3159, 0,4815)	(0,3135, 0,4812)	(0,3145, 0,4821)	(0,3332, 0,5230)	(0,3330, 0,5233)	(0,4482, 0,7398)	(0,4497, 0,7417)
CCT [T_{cp}] Unit : K	6 331,1	6 451,9	6 398,4	5 469,5	5 479,6	2 850,6	2 827,9
Duv	0,0018	0,0035	0,0031	0,0035	0,0038	0,0002	0,0000

Evaluation method for colour target spectral distribution

In case of colour target, there are two metrics such as S_{R2} and CIEDE2000

$$S_{R2} = \frac{\sum_{i=1}^{N} \left(\left(\rho_{ri} - \rho_{gi} \right) \left(L'_{ri} / Y'_{L} \right) \right)^2}{N} \qquad Y'_{L} = \sum_{i=1}^{N} V_{ri} L'_{ri} \qquad \sum_{i=1}^{N} V_{ri} = 1$$

L'_{ri} is the reference light spectrum of the *i*-th wavelength

$L'_{ri} = Lri / Ps$

r_{ri} is the reference colour target spectrum of the *i*-th wavelength

r_{gi} is the spectrum of the *i*-th wavelength generated by the light emission system

$r_{gi} = E_{gi} / L'_{ri}$

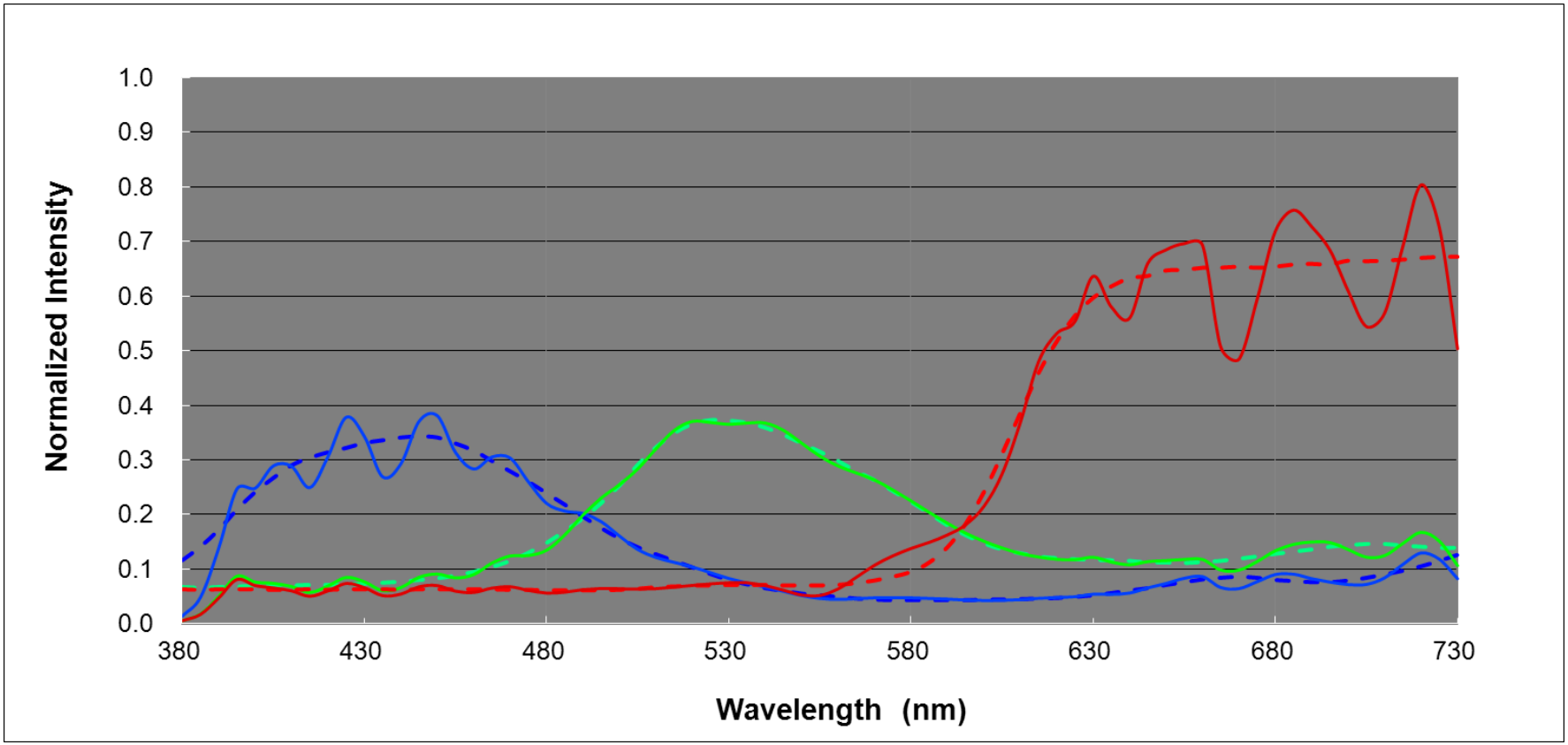
Note : r_{ri} and r_{gi} are corresponding to reflectance or transmittance.

V_{ri} is the normalized-response of the *i*-th wavelength derived from the luminosity function,

Y'_{L} is the normalization factor to remove light source dependence,

CIEDE2000 is calculated using r_{ri} , r_{gi} and light source.

Colour targets : RGB

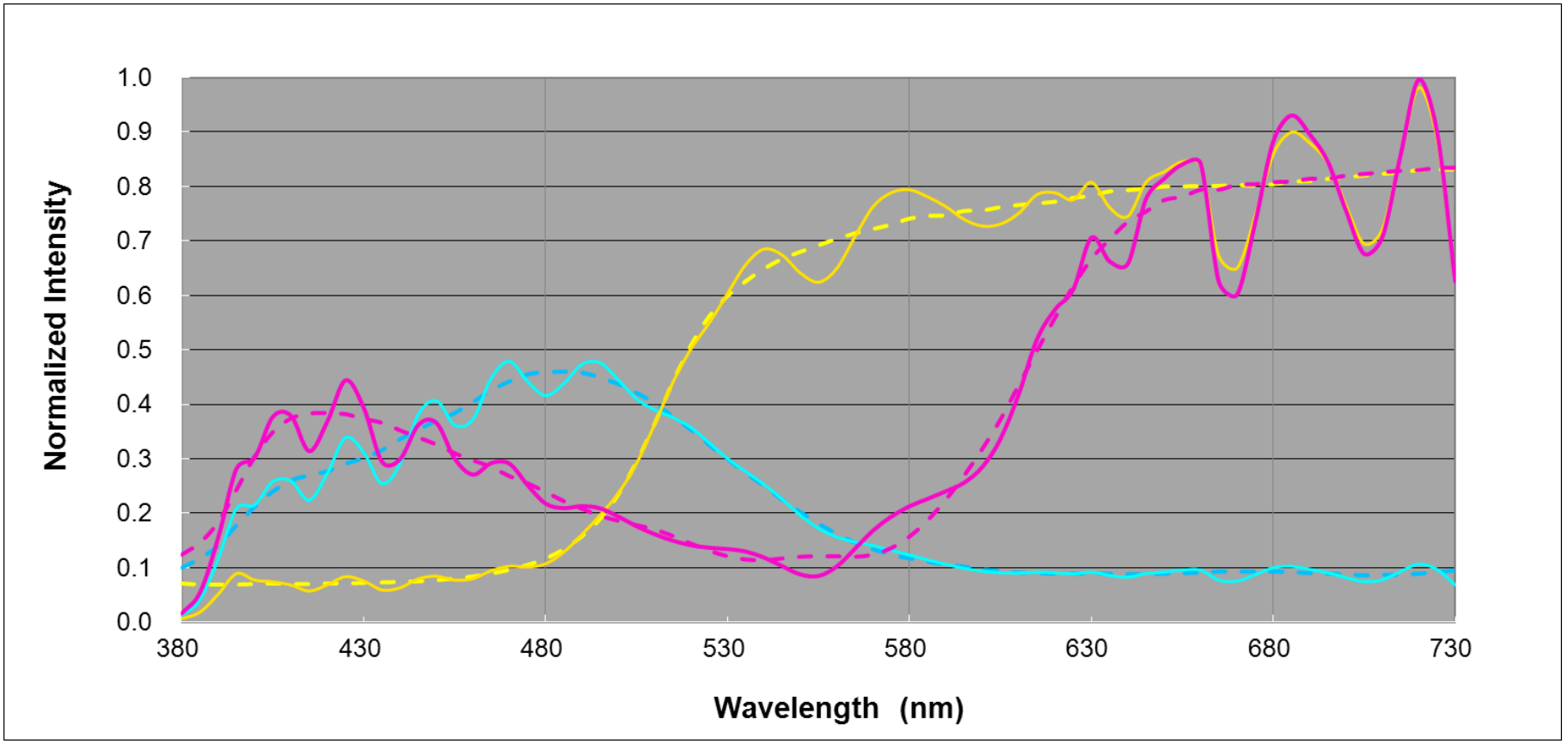


Solid line : generated distribution

Dotted line : reference

	SR2	DE2000
B	0.00063	0.165
G	0.00019	0.108
R	0.00253	0.858

Colour targets : CMY



Solid line : generated distribution
Dotted line : reference

	SR2	DE2000
Y	0.00278	0.074
M	0.00419	0.596
C	0.00053	0.285

3. Error analysis of the process -- 1 – error factors

Process & Error factor	Process-1: Reference → Calculated data Variables : Number of LEDs, Optimization error	Process-2: Calculated data → binary data for output Variables : Linearity of light intensity, Bit depth(resolution)	Process-3: Binary data → Measured data Variables : Stability, Reproducibility, Accuracy of measurement , e.t.c.

Bigger contribution factors to Error

Numbers of LEDs and Bit-depth

Smaller contribution factors to Error

Optimization error, Stability & Reproducibility, Accuracy of measurement,

Error analysis of the process -- 2-1 -- Number of LEDs

Select best SR2 among several candidates

Then Add constraint : added DE2000<=1.5 to optimization

No constraint	14LEDs		12LEDs		10LEDs		8LEDs	
	SR2	DE2000	SR2	DE2000	SR2	DE2000	SR2	DE2000
Max	0.0045	1.37	0.0055	2.44	0.0096	3.18	0.0085	5.23
Average	0.0012	0.49	0.0013	0.63	0.0026	0.77	0.0028	1.6
constraint								
Max	0.0045	1.37	0.0065	1.5	0.0096	1.5	0.0448	1.5
Average	0.0012	0.49	0.0014	0.58	0.0026	0.58	0.0051	0.87
Requirement	SHALL		SHOULD					
Average	0.003	1.6	0.0016	0.8				
Max	0.01	5	0.005	3				

Error analysis of the process -- 2-2 -- Number of LEDs

Conclusion

- “Adding constraint” makes subtle SR2 increase but smaller DE2000.
- “Adding constraint” is very effective.

SR2 value is very dependent on number of LEDs.

Error analysis of the process – 3-1 -- Bit-depth

	10LEDs				12LEDs				14LEDs				
DE2000	8bit	9bit	10bit	∞	8bit	9bit	10bit	∞	6bit	7bit	8bit	10bit	∞
Average	1.14	0.54	0.25	0.61	0.77	0.4	0.18	0.5	2.51	1.42	0.72	0.18	0.5
Max	3.67	1.83	0.73	1.5	2.2	1.14	0.62	1.5	9.37	3.77	1.74	0.49	1.5
Average2	1.29	0.82	0.66		0.92	0.64	0.53		2.56	1.51	0.88	0.53	
Max2	3.96	2.36	1.67		2.67	1.89	1.62		9.49	4.06	2.3	1.58	
requirement													
SHALL	Average	1.6											
	Max	5											
SHOULD	Average	0.8											
	Max	3											

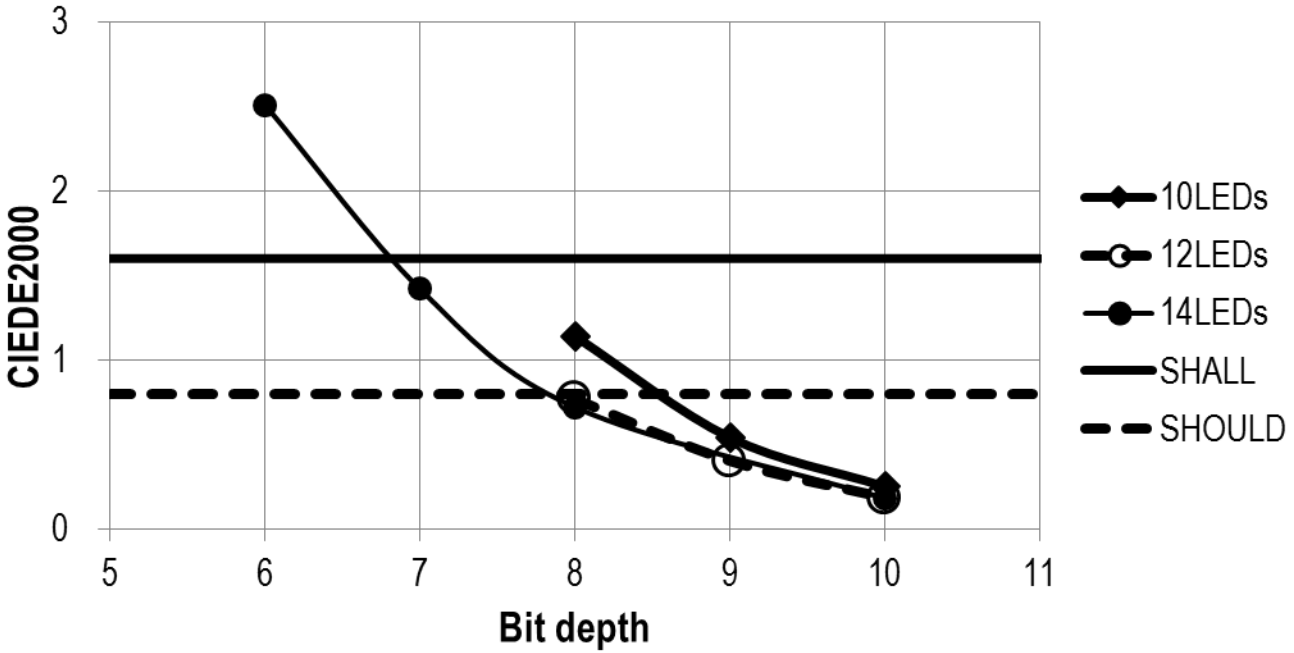
Consideration

It is better to use measured spectra because of the difference between reference and calculated data.

DE2000 is very dependent on Bit-depth.

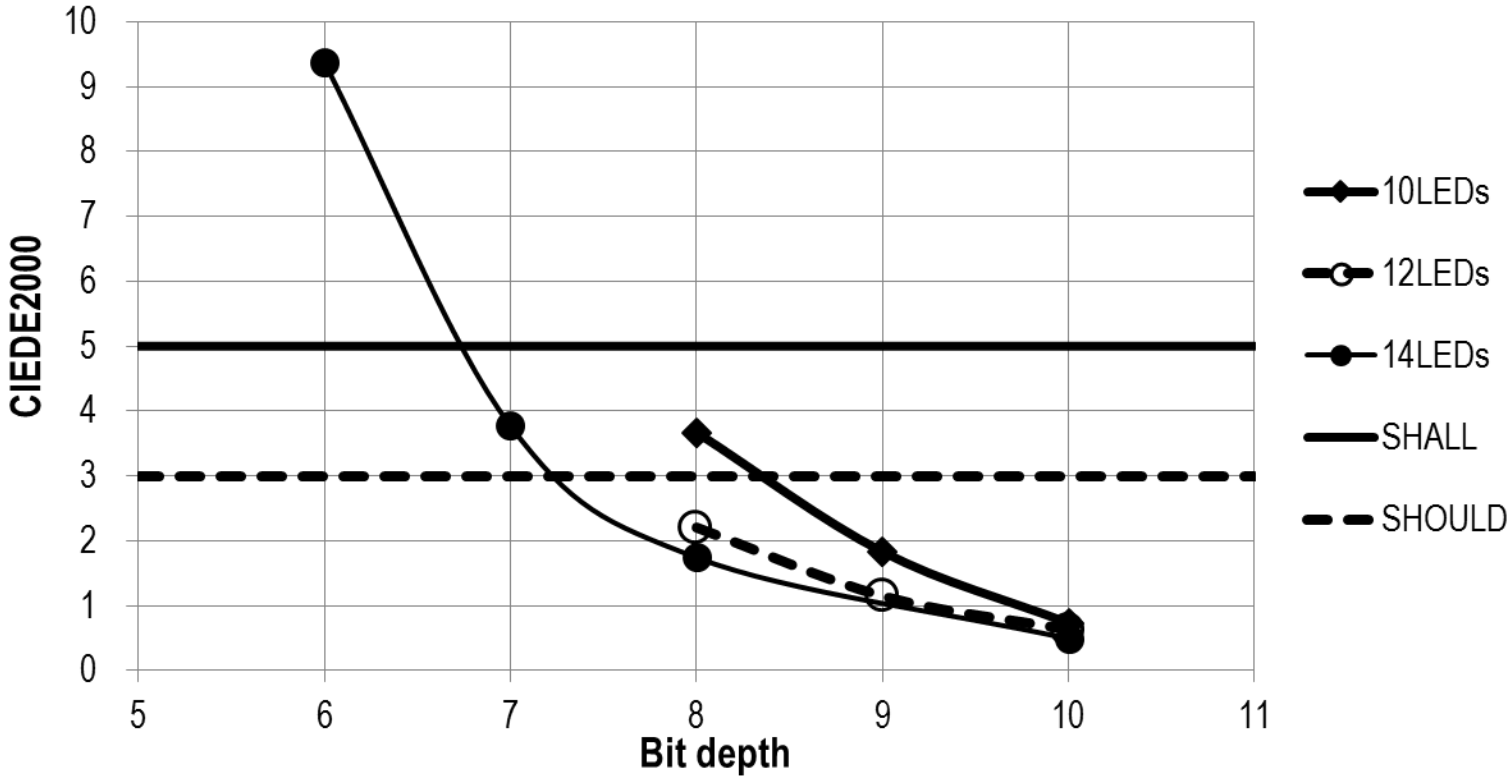
10 bit is “SHALL. 12 bit is “SHOULD”

Error analysis of the process -- 3-2 -- Bit-depth



Relationship between Bit depth and average DE2000 for 24 colours of Color Checker Classic

Error analysis of the process -- 3-3 -- Bit-depth



Relationship between Bit depth and maximum DE2000 for 24 colours of Color Checker Classic

Error analysis of the process – 4 -- summary

SR2 value is very dependent on number of LEDs.

“Adding constraint” is very effective. → Annex B

SR2 metric is “to estimate ability of spectral distribution generation using programmable light emission system.

DE2000 is very dependent on Bit-depth.

10 bit is “SHALL. 12 bit is “SHOULD”.

It is better to use measured spectra because of the difference between reference and calculated data.

4. Optimization method -- 1 – Stepwise LSQ (Least Square method)

Optimization is so important in this study.

Algebraic approach : stepwise LSQ

Obtain LED intensities using LSQ

No negative intensity → this is the solution

One negative intensity → to remove this LED and re-calculate LSQ without this LED → then solution

Plural negative intensities → Check whether negative intensity exists or not for all of combinations (${}_nC_{m-1}$=n!/((n-m+1)! (m-1)!, n: number of LEDs, m:number of negatives)

No negative intensity → this is the solution

Remove these LEDs and iterate this procedure

Optimization method -- 2 --

GRG(Generalized Reduced Gradient algorithm) approach : Eric's suggestion in Cologne meeting.

To obtain LED intensities using LSQ

To set zero instead of negative value and do GRG

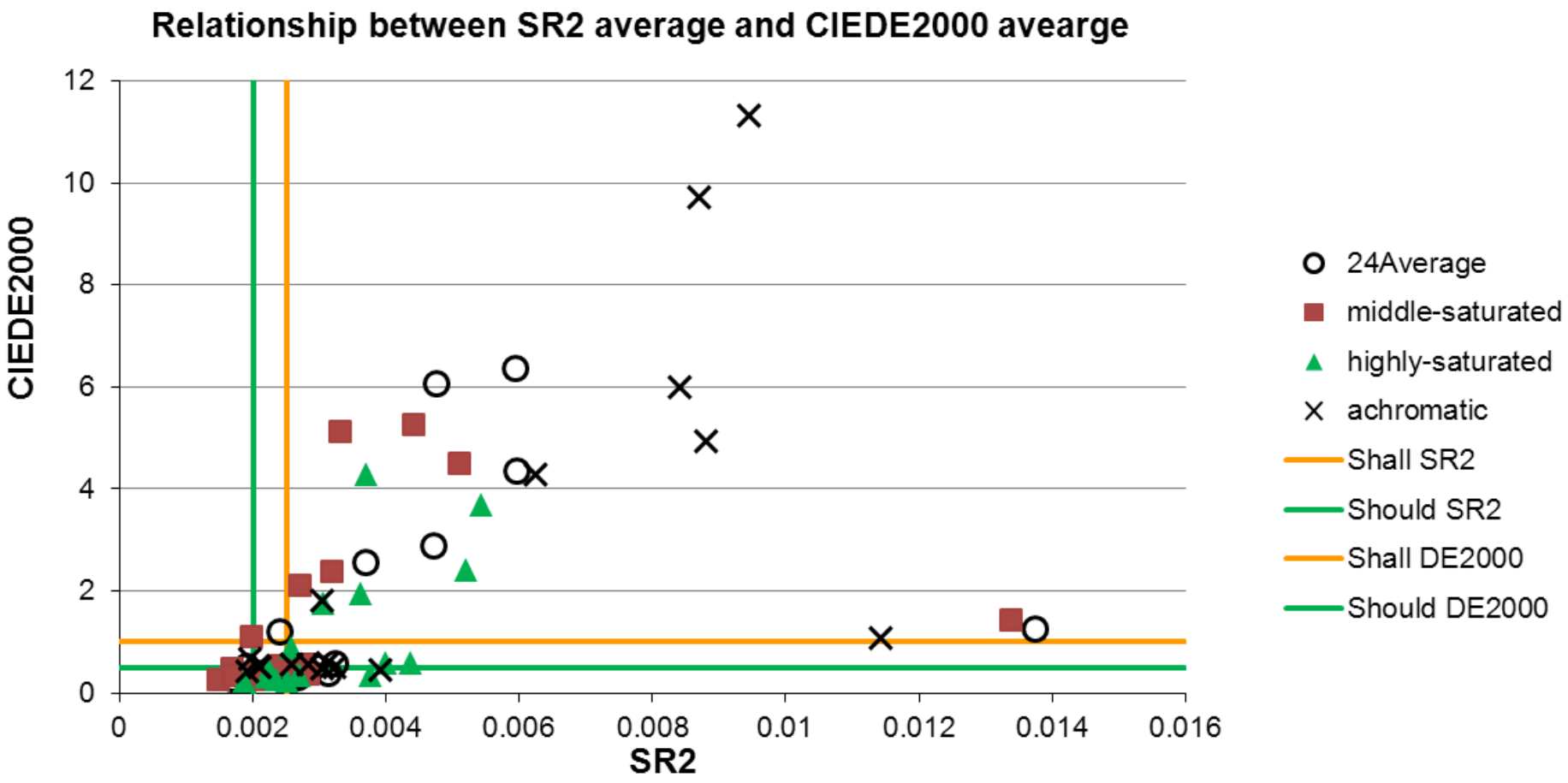
Characteristics & Comparison

Algebraic approach : perfect solution but complicated & time-consuming

GRG approach : almost(pseud)- perfect solution and easy procedure

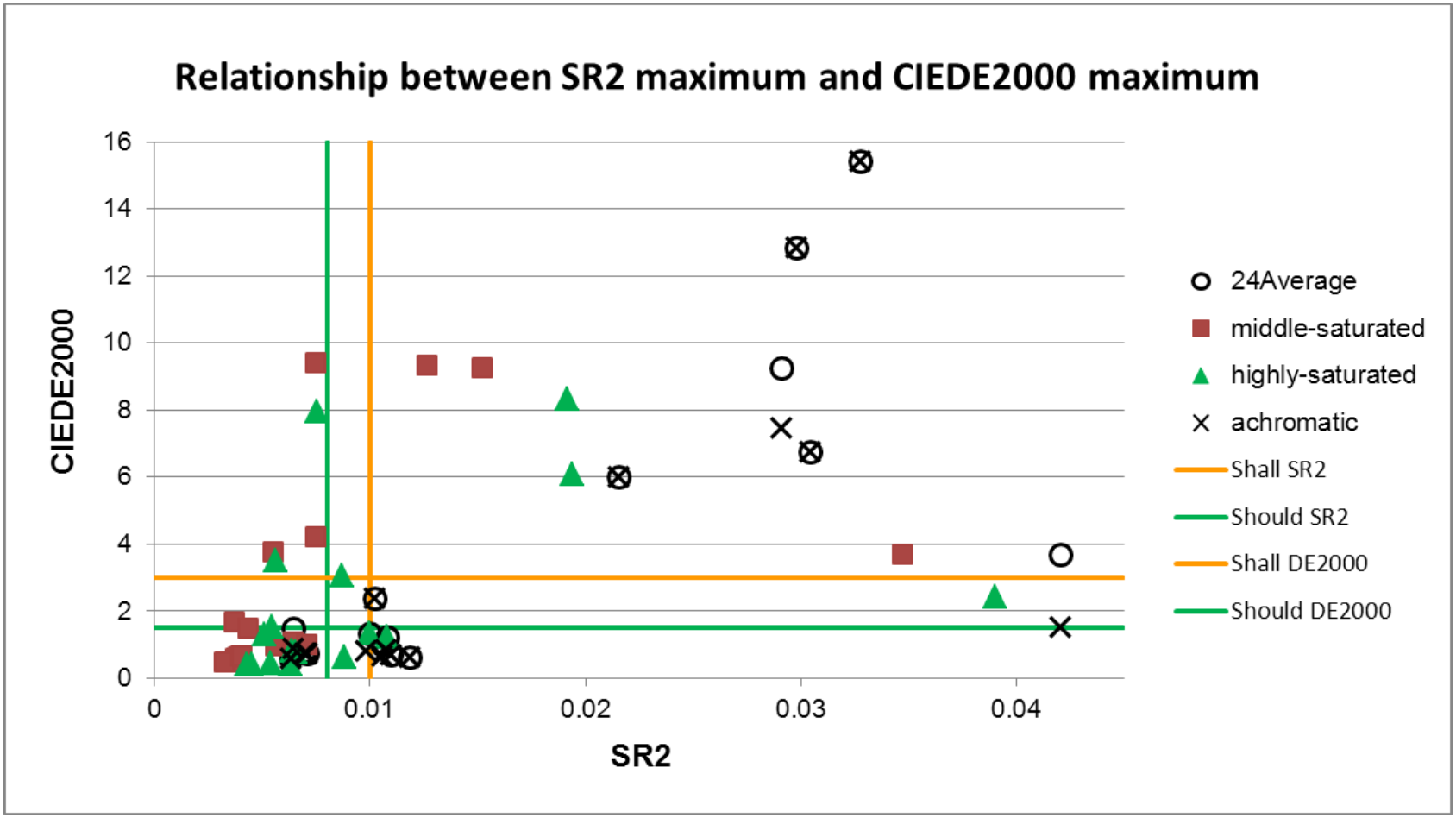
Note : GRG is very dependent on initial LEDs intensities. So, LSQ method is very important.

Relationship between SR2 and CIEDE2000 averages



Number of combination is ${}_{18}C_1 = 18$.

Relationship between SR2 and CIEDE2000 maximums



17 LEDs set is selected for 18 LEDs.
Number of combination is ${}_{18}C_1 = 18$.
SR2 and DE2000 for 18 combinations are calculated.

Recommendation for colorimetric image capture

Annex E (informative) shows the followings.

S_{R2}	**Average value for colour targets**	**=< 0,0018**
	Maximum value for colour targets	=< 0,0072
CIEDE2000	Average value for colour targets	=< 0,50
	Maximum value for colour targets	=< 1,50

Key for success and summary

Key for success

Non-linear optimization method (GRG) & initial values of LED intensity

Francisco Imai's paper : Comparative Study of Metrics for Spectral Match Quality, CGIV 2002

delta-E, RMS, metamerism index, correlation

and weighted-RMS

-> RMS is the best.

We have developed design method and evaluation metrics of spectral distribution for LED colour generator

5. Applications -- 1 --

- SOCS(ISO/TR 16066): over 53000 spectral distributions

  SR2 average = 0.000675,

  DE2000 average = 0.230 for 18 LEDs

- ITU-R BT.2020 : That is 8K-Laser TV.

	x	y
R	0.708	0.292
G	0.170	0.797
B	0.131	0.046
W(D65)	0.3127	0.3290

Colour targets for image capturing system

more high-saturated than reflective colour targets

PC-control that is automatic

Applications -- 2 --

Monitor

- Spectral distribution is better than RGB additive colour.
- Can remove individual difference
- Stable
- Metamerism reserch

More severe applications such as

- Cosmetic, Car(metallic coating)
- Medical

Can meet icc-MAX procedure

Appendix --- Weighted-RMS method -1-

Francisco Imai's paper : Comparative Study of Metrics for Spectral Match Quality, CGIV 2002

Four kinds of metrics such as delta-E, RMS, metamerism index and weighted-RMS

There is no best method. It's dependent on application.

This report is very consistent with our experiences.

Weighted-RMS might be better than just RMS such as SR2.

Weighted-RMS method -1-

Two approaches

A: $W_{invR}(\lambda)=1/\rho_g$

Human visual system is more sensitive to mismatches in dark colours than light colours.

B: Diagonal matrix [R] =A*inv(A^t*A)*A^t

$W_{diagR}(\lambda)$=diag([R])

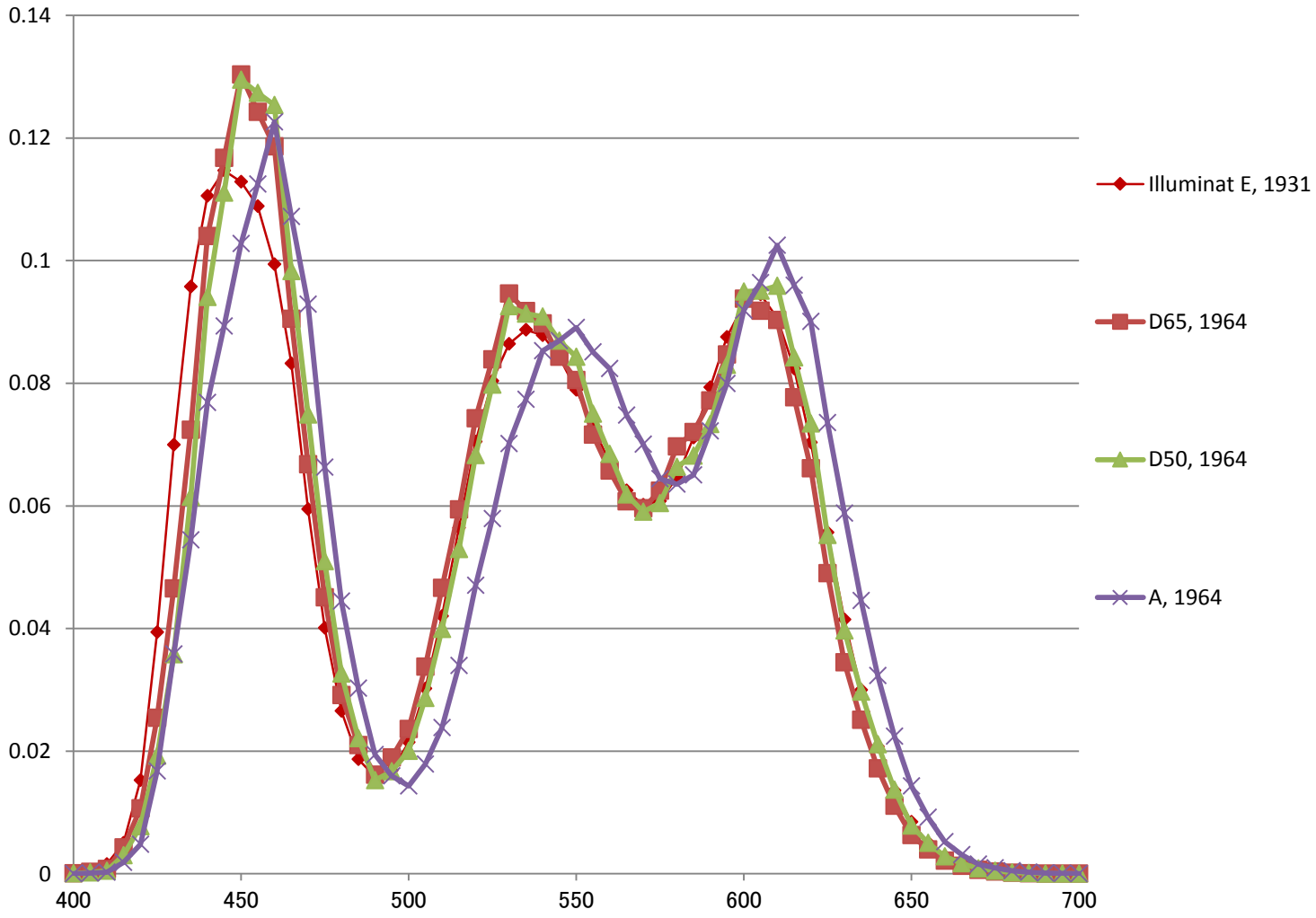
(Weighted-RMS)**2= $S_{R2}=\frac{\sum_{i=1}^{N} Wi\left(\rho_{ti}-\rho_{gi}\right)^2}{N}$

Urabe's approach

A' : $W(\lambda)=Log_{10}(1/\rho_g)$

Prof. Ohta said No need to use.

Weighted-RMS method -2-



Weighting function for several cases

Weighted-RMS method -3-

Effectiveness of weighting function														
	18 LED	17 LED	16 LED	15 LED	14 LED	13 LED	12 LED	11 LED	10 LED	9 LED	8 LED			
Macbeth	effective or not		1:effective		0: Not									
1:dark skin	1	1	1	1	1	1	1	1	1	1	1		1:dark skin	11
2:light skin	1	1	1	1	1	1	1	1	1	1	1		2:light skin	11
3:blue sky	0	1	1	1	1	1	1	1	1	1	1		3:blue sky	10
4:foliage	1	1	0	0	0	0	0	0	0	1	1		4:foliage	4
5:blue flower	1	0	0	1	1	1	1	1	1	1	0		5:blue flower	8
6:bluish green	1	1	1	1	1	1	1	1	1	1	1		6:bluish green	11
7:orange	1	1	1	1	1	1	1	1	0	0	1		7:orange	9
8:purplish blue	0	0	1	1	1	1	1	1	0	1	0		8:purplish blue	7
9:moderate red	1	1	1	1	1	1	1	1	1	1	0		9:moderate red	10
10:purple	1	1	0	1	1	1	1	1	1	0	0		10:purple	8
11:yellow green	0	0	0	1	1	1	0	0	0	0	0		11:yellow green	3
12:orange yellow	0	0	0	0	0	0	0	0	0	0	0		12:orange yellow	0
13:blue	0	0	0	0	0	1	0	0	0	0	0		13:blue	1
14:green	1	1	1	1	1	0	0	0	0	1	1		14:green	7
15:red	1	1	1	1	1	1	1	1	1	1	0		15:red	10
16:yellow	1	1	1	1	1	1	1	1	1	0	0		16:yellow	9
17:magenta	1	1	1	1	1	1	1	1	1	1	0		17:magenta	10
18:cyan	1	1	1	1	1	1	1	1	1	1	1		18:cyan	11
19:white	0	0	0	1	1	1	1	1	1	1	1		19:white	8
20:nutral8.5	0	0	0	1	1	1	1	1	1	1	1		20:nutral8.5	8
21:nutral6.5	1	0	0	1	1	1	1	1	1	1	1		21:nutral6.5	9
22:nutral5	0	0	1	1	1	1	1	1	1	1	1		22:nutral5	9
23:nutral3.5	0	0	0	1	1	1	1	1	1	1	1		23:nutral3.5	8
24:black	0	0	0	0	0	1	1	1	1	1	1		24:black	6
SUM	14	13	13	20	20	21	19	19	17	18	14			
													denominator	N=11
														%
													middle 1-12	69.7
													high 13-19	72.73
													grey 19-24	72.73

Conclusion : will not be added to next draft

How to determine SR2 requirement values

Report in Cologne meeting :

SR2 value is very dependent on number of LEDs.

Note : “wider wavelength range” requests more number of LEDs.

Removed one LED having the smallest contribution using Annex B procedure

18 → 17 : 18 combinations

17 → 16 : 17 combinations

16 → 15 : 16 combinations

15 → 14 : 15 combinations → Total : 66 combinations

Calculated SR2&DE2000 of each combination for Macbeth

DE2000 requirements

Decide “psychophysical” metrics at first then “physical”

- “Should” requirement of the average DE2000

1. Based on discrimination threshold of colour difference between patches put side by side: 1.2 of DE76.

2. Convert 1.2 of DE76 into a value of DE2000.
   1.2 X 0.7 = 0.84

3. Take a margin of 1/2 and round.
   0.84 / 2 >>>0.5 “should” restriction

Max. DE2000 is set to three times of
Ave. DE2000>>> 1.5 DE2000

- “Shall” requirements of an ave. and a max. DE2000

1. Two times of the each requirement.
   Ave. DE2000 is 1.0 and max. DE2000 is 3.0.

SR2 & DE2000 requirements (DE04)

Average

	Average	50% percentile	67% percentile	WD8 spec	WD9 spec
SR2 DE2000 SHALL	0.00261 0.599 (number=15)	0.00254	0.00297	0.0025 1.00	0.0025 1.00
SR2 DE2000 SHOULD	0.00216 0.364 (number=23)	0.00222	0.00265	0.0018 0.50	0.0020 0.50

Max

	Average	50% percentile	67% percentile	WD8 spec	WD9 spec
SR2 DE2000 SHALL	0.00889 1.485 (number=22)	0.00986 2.355	0.00102 2.382	0.0100 3.00	0.0100 3.00
SR2 DE2000 SHOULD	0.00877 0.741 (number=18)	0.00743 0.771	0.01055 0.993	0.0075 1.50	0.0080 1.50

UNIVERSITY OF WESTMINSTER

Skin Colour Reproduction on LCDs

Aim:

- To investigate the accuracy of reproduction of skin colours including skin affected by medical conditions on displays used in medical imaging.
- To apply the findings in recommending optimal workflow and viewing conditions for dermatology images viewed on LCDs.

Dr Efthimia Bilissi (E.Bilissi02@westminster.ac.uk)
Imaging Technology Research Group, University of Westminster

Proposed stages

- Determination of the colour gamut of healthy skin and skin conditions.

  -Literature search for prior work on definition and modelling of skin colour gamut for applications in dermatology.

  -Colour measurements of skin with medical conditions to determine changes in colour compared to healthy skin.

The main interest is in the gamut boundaries rather than specific skin colours.

Work on a skin database is currently being carried out by Kaida Xiao (University of Liverpool) and CIE (TC 1-92 Skin Color Database).

Proposed stages

- Objective measurements of colour differences and subjective measurements of colour discrimination within the specific skin colour gamut, using colour patches displayed on LCDs.
- To explore the possibility of conducting subjective tests using real medical images.
- Recommendations for optimal workflow and viewing conditions for dermatology images.

Dr Efthimia Bilissi (E.Bilissi02@westminster.ac.uk)
Imaging Technology Research Group, University of Westminster

Additional comments

- What is the problem that you are trying to solve?
  - Determining whether the accuracy of reproduced colour in the region of skin tones using a colour managed image capture and display system can be improved and if such an improvement is possible, to determine if this will assist in diagnosing skin related problems
  - Conduct a survey with clinicians to determine whether they currently experience problems in accurately diagnosing skin problems from images displayed on calibrated monitors.
- Can you explain why is the gamut important?
  - I agree that skin colours are expected to be within the display gamut
  - By defining the region of the CIELAB colour space where skin colours are located, I would be able to do a more in depth investigation on viewers' perceptibility of skin colour differences.
- Uniform colour patches may be a poor simulation for skin
  - I agree that it may be a poor simulation from the perspective of texture
  - I have also been considering the use of patches which are actual photographs of skin areas, with as uniform colour as possible

ICC Medical Imaging Working Group meeting

“Discussion of the draft recommendations of the ICC MIWG Displays”

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

June 10th 2015

Tokyo

Goal of mRGB group

- Problem to be solved: “There is no suitable color space and display calibration objective for medical imaging displays designed to display color medical images”

- Group activities
  - Educate
  - Standardize
  - Expose
  - Promote metrics

Summary of the activities so far (1)

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

- How to color calibrate medical display systems? => perceptually linear color calibration
  (to be further worked out)

Summary of the activities so far (2)

- How can we ensure consistent and accurate greyscale and color representation of medical images on color displays?
  => Draft recommendations for *greyscale* images (GSDF) on color displays
  => After that: final recommendations for *greyscale and color* images

Conclusions of Kuurne meeting

- During the Kuurne meeting, many bench testing and simulation results were presented related to visualization of medical greyscale images on color displays.
- The ICC MIWG found these results sound and requested to summarize the results in a “draft recommendation document” and distribute it for review

  This draft was distributed on May 28th 2015 and feedback was accepted until June 8th 2015.

Goal of today's discussion

- Statistics of comments received
- Summary of the draft recommendations
  (with most comments already taken into account)
- Formally approve the draft recommendations

Feedback received

- 6 people provided feedback
- In total around 27 different comments were received
  - Terminology/wording
  - Better positioning of the work in relation to the use cases
  - Clarifications on the figures
  - Clarifications how the ICC profiles were generated and what type of profiles were used
  - Questions on test methodology
  - ...

- Most of these comments have been included already in a revised version (and also in the following slides that summarize the recommendations)
- A small number of comments are still being discussed because of their highly detailed technical nature

Scope of this draft

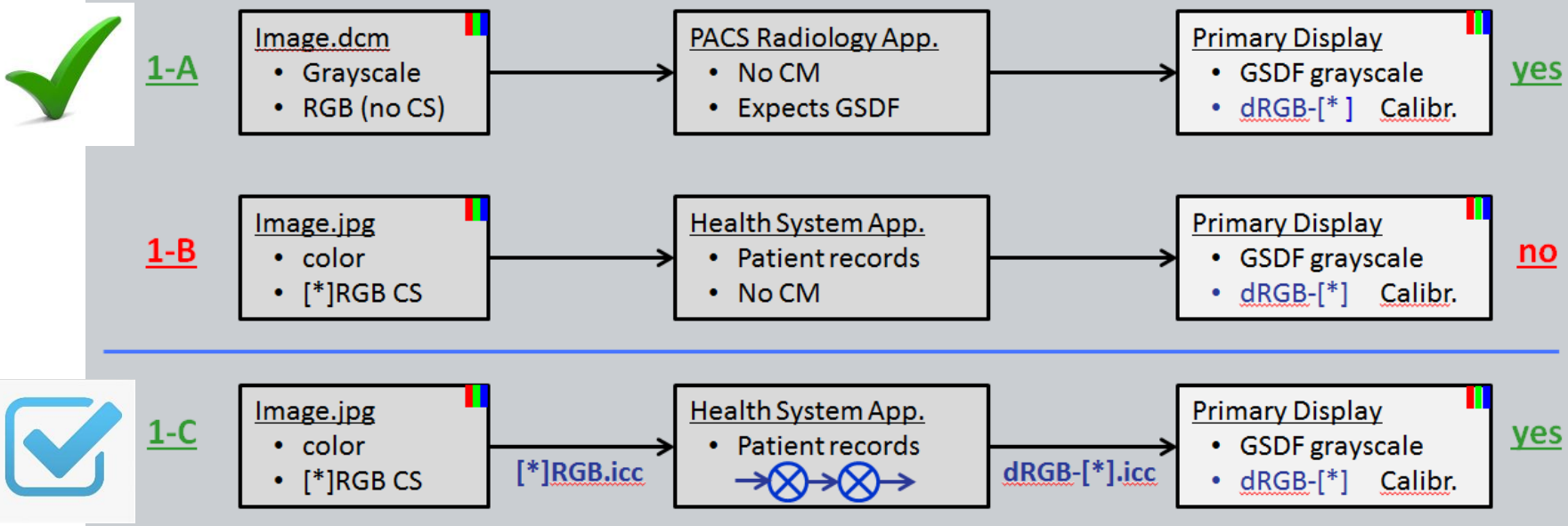
- Link with the use cases defined in dRGB

– Indicates within scope of current draft recommendations (presentation of greyscale medical images in line with GSDF on color medical displays)

– Indicates within scope of final recommendations (when draft is extended to presentation of greyscale and color medical images on color medical displays)

Case 1 – Primary display, radiologist workstation

1. Medical image presentation on a workstation with DICOM calibrated primary monitors used for medical interpretations



Case A:	Correct	Grayscale & pseudo-color DICOM images with GSDF neutral tones.
Case B:	Incorrect	Color photograph is presented with GSDF neutral tones.
Case C:	Correct	Color photograph is presented with the intended color space.

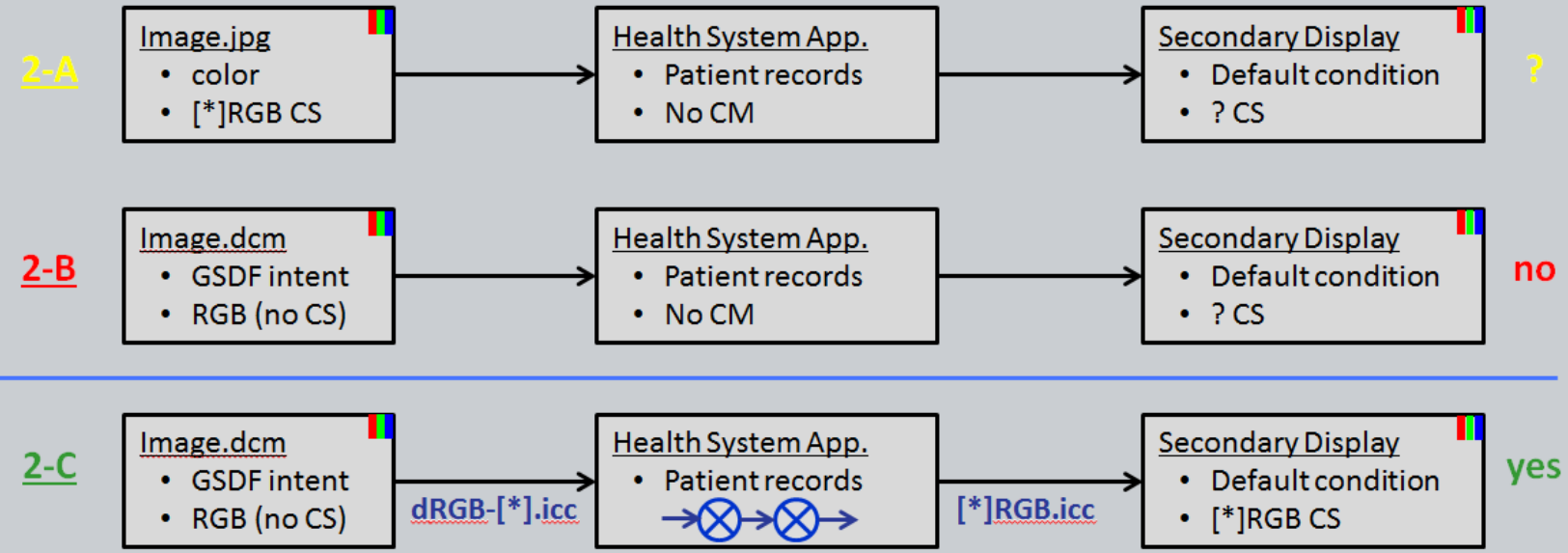
Denotes a color managed module
Using source and display profiles

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

Slide courtesy of Mike Flynn

Case 2 – Secondary display, physician workstation

2. Medical image presentation on a workstation with secondary monitors used for reviewing patient information.



Case A:	Uncertain	Color photograph is presented with the default configuration .
Case B:	Incorrect	Grayscale & pseudo-color DICOM images not presented with GSDF.
Case C:	Correct	Grayscale & pseudo-color DICOM images are mapped to GSDF

Denotes a color managed module
Using source and display profiles

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

Slide courtesy of Mike Flynn

Summary draft recommendations (1)

- For medical display systems which already have embedded DICOM GSDF calibration and stabilization, it is recommended to disable the CMM or make sure that an identity profile is used.
- For non-stabilized or non-calibrated displays, the following recommendations are provided with the goal to stay within 10% tolerance of the DICOM GSDF target.

Summary draft recommendations (2)

- System configuration
  - Only use ICC profiles that have been specifically created for the specific display being used. Generic profiles do not offer sufficient accuracy.
  - Every time a display setting is changed (eg. display luminance or contrast settings), a new profile needs to be created and used.
  - Use at least $10\ bits$ connections from application to software, as Table 8 shows $8\ bits$ are clearly not enough.
  - 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.

- ICC Profile and CMM
  - Both input and display profiles must take the ambient light into account.
  - The input profile must be a Monochrome profile. DICOM Calibration is only about the luminance of gray levels, even on color displays. Monochrome profiles do not suffer from the cross talk of LCD panels and offer the possibility to have much more data on gray than LUT based profiles. See table 7.
  - If LUT-based, the display profile must have LUT of at least 65^3 points. See table 7.
  - An important attention must be given to the PCS-To-Device conversion of the Black point. This is critical to achieve an acceptable calibration. See section 6.2.

Summary draft recommendations (3)

- Calibration process
  - The calibration process must be repeated at least every 50 days since display behavior changes over time as figure 14 shows. This means renewing display measurements and regenerating the display profile based on these measurements.
  - The ambient light must be stable, or the calibration process must be repeated several times a day. See figure 20.

Formal approval

Next steps (1)

- Tom Kimpe will distribute the revised draft recommendations document
- Paper presentation at AAPM 2015 on behalf of the ICC MIWG

ICC MIWG Displays: Draft Recommendations for a Color Visualization Pipeline

T Kimpe[1]*, M Flynn[2] , (1) Barco Healthcare, Kortrijk, Belgium (2) Henry Ford Health System, Detroit, MI

Presentations

WE-D-204-1 (Wednesday, July 15, 2015) 11:00 AM - 12:15 PM Room: 204

Purpose:
Use of color images in medical imaging has increased significantly. As of today there is no agreement on what is an appropriate visualization framework for color medical images, resulting into large variability of color appearance and it making consistency and quality assurance a challenge.
The ICC Medical Imaging Working Group (MIWG) [http://www.color.org/groups/medical/medical_imaging_wg.xalter] is working towards recommendations and standards for visualizing color medical images.

Methods:
The MIWG collected color characterization data for a wide range of color displays (consumer, professional and medical), as well as a collection of representative greyscale and color medical images. Based on this, simulations and bench testing was done to quantitatively compare the performance of various architectures and imaging pipelines. This allows making recommendations on imaging pipeline architectures, and defining minimum requirements to guarantee minimum performance levels.

Results:
Preliminary results are available already, and more complete results will be available before the AAPM annual meeting. Results so far suggest that, if appropriate choices are made for the imaging pipeline, it is possible to use the ICC framework in a medical context and obtain accurate visualization of greyscale (DICOM GSDF compliance) and color medical images.
But performance heavily depends on specific choices made in the imaging chain. Eg. the effective bit depth of the display link has a large impact on performance, small changes in display tone rendering curve have a significant negative effect on compliance to DICOM GSDF, etc.
At the AAPM annual meeting, more complete results and draft recommendations will be available.

Conclusion:
There is a need to standardize how medical color images need to be visualized. The ICC Medical Imaging Working Group is working towards recommendations for a visualization framework for color medical images that extends the current grey image framework and so will allow both color and grey images to be displayed simultaneously.

Next steps (2)

- Extend the draft recommendations
  - visualization of medical color images
    - Further work will be done by the group to cover the additional use cases as described in dRGB (Mike Flynn)
  - perceptually linear color visualization
    - As agreed in Kuurne, Barco is preparing a journal paper with all details
  - Align with the work on dRGB to make sure perceptually linear presentation can be a tag

Questions?

(tom.kimpe@barco.com)