Medical Imaging Working Group

The Westgate Hotel
1055 Second Avenue
San Diego, CA 92101
5 November 2016

Craig Revie, MIWG chair, opened the meeting at 13:45 and following self-introductions and a sound check for those on-line, he introduced the agenda as follows:

1. Introduction
2. Colour calibration for Petri dish imaging
3. Gjøvik masters course on colour in medical imaging
4. Updating FAQ 'How do I assess the accuracy of a display profile?'
5. Medical photography white paper
6. How to determine the gamut boundary of a display profile
7. Skin imaging update
8. Action items review

1. Introduction

Mr Revie gave the background to MIWG, and the initial meeting in conjunction with the FDA who recognise the importance of colour in medical imaging. Issues addressed so far by MIWG include calibration of whole-slide imaging scanners, medical displays (where Barco collaborated on development of ICC White Paper 44), skin imaging, mobile imaging (currently paused), and multispectral imaging, which is relevant to several imaging modalities such as WSI, Petri dish imaging etc. The MIWG web site is kept up to date and hosts a great deal of useful material.

2. Colour calibration for Petri dish imaging

Jeremie Pescatore provided an update in microbiology imaging [see attached]. His company, Biomerieux, have several partners in this work. The goal is essentially equivalence between manual and virtual (i.e. image-based) reading, with consistent diagnostic value. A calibration module computes a custom ICC profile, and CIECAM02 has been implemented to predict perceived colour. The system measures a spectral hypercube, and in the calibration they measure the spectral sensitivity of the sensor. The calibration tool is Matlab-based, and makes v2 Input class Lut profiles by calling Argyll. The calibration target is a colorchecker with additional colours from microbiology plates.

Dr Pescatore showed results from calibrating with both the target-based and spectral sensitivity method, with 240 training measurements. Accuracy was approximately 2 units of CIELAB 1976 colour difference, and the performance of the spectral method was equivalent to the chart-based method. Using training samples from microbiology in place of a standard calibration target gave better results.

Based on the results, Dr Pescatore proposed to develop a primer on microbiology calibration, together with three other White Papers. Open issues were that there may need to be reserved IP for the spectral calibration methods, the virtual target and the Matlab tool. Jack Holm stated that the methods are as described in ISO 17321-2.

Dr Pescatore stated that the camera sensitivity was measured with a monochromator, as this had been found to give better results than using Image Engineering IQ-LED system. The measurement includes the effect of the system optics.

He proposed to complete the primer for the next ICC meeting, with a draft by the end of December. It was noted that White Papers would need review within ICC and MIWG.

3. Gjøvik masters course on colour in medical imaging

Dr Phil Green stated that a new graduate course in Colour in Medical Imaging was being offered by NTNU in Gjøvik, Norway, as part of the European Erasmus Mundus Master programme on Colour in Science and Industry [see attached]. Projects in collaboration with vendors and institutions in medical field were welcome.

4. FAQ on display profile accuracy

Dr Green had developed a brief FAQ item at http://www.color.org/faqs.xalter#pa6 on assessing the accuracy of a display profile, and at previous meetings it had been decided to expand this and develop a White Paper on the topic. There was no progress to report on this activity.

5. Medical photography white paper

The status of the document, now titled ‘Improving Color Image Quality in Medicine Photography’, was summarised. Dr John Penczek had provided a complete draft [see attached] which includes all the previously outstanding sections and some new material, and this had been circulated prior to the meeting.

The MIWG page on this topic had been updated with some additional example images, and Yves Vander Haeghen proposed adding more images which he undertook to provide.

The main comment from the meeting was that the recommended procedures for scene-referred camera output are already described in TC42 standards especially ISO 17321.

It was noted that some cameras such as the iPhone7 were able to save DNG format images, which would support RAW processing for such devices which normally just save rendered JPEGs.

The following undertook to review the draft and provide comments: James Vogh, Eric Walowit, Jack Holm, Ray Cheydleur, and Chris Bai.

6. Display profile gamut

It had been suggested that it would be useful to develop an FAQ on determining the gamut of a display. Dr Green had prepared a draft FAQ at http://www.color.org/displaygamutfaq.xalter, and comments are welcome. It was suggested that an iccMAX gamutBoundaryDescType should be included.

7. Skin imaging

Dr Kaida Xiao presented an update of the work on skin imaging [see attached], which is being undertaken within a CIE TC. He summarised the objectives and described the value of having spectral reflectance rather than colorimetry. In his approach the camera sensitivity functions provided a basis for estimating reflectance, using the skin spectral database the method and PCA to determine basis functions. His results showed that this gave better results than a two-step method and preserves skin spectral reflectance well. One application currently is to look at the reflectance before and after exercise.

The meeting discussed the spectral measurement procedure used to provide training data. Dr Xiao stated that both specular included and excluded measurements had been made, and in contact measurements the effect of pressure was negligible. It was difficult to conclude whether a TSR was better than a spectrophotometer for this purpose. The error was typically below 3 units of CIE 1976 colour difference.

Dr Holm stated that in his experience a TSR gave better results, and the scattering was illumination dependent. The difference between a calibrated camera and a TSR was generally around 1.5 units in CIELAB colour difference.

One goal of Dr Xiao's work was to match silicone-based prosthetics, although it was acknowledged that human skin has different scattering and reflection properties to synthetic materials. He stated that the CIE TC will close in 2017, and the full reflectance spectra would be made publicly available in 2017.

8. Action items review

Craig Revie reviewed outstanding MIWG action items [see attached]. Many were closed, and the meeting discussed the following:

8.1 MIWG-15-34 Provide input on calibration errors using different types of training sets (Holm / Walowit)

Dr Holm and Dr Walowit stated that they have test functions, and their experience was that different training sets do affect the maximum errors. The meeting noted that it was a goal to cite published result which support this.

8.2 MIWG-16-11 Provide document on camera calibration research project for ICC web site (Vander Haeghen)

Dr Vander Haeghen agreed to provide this (possibly edited due to IP).

8.3 MIWG-16-12 Discuss ICS for GSDF and report back to MIWG (Bai, Derhak, Nagashima-san and Kimpe)

Chris Bai undertook to lead on developing the ICS

There being no further business, the meeting closed at 17:00.

Action items

The following action items were agreed at the meeting:

MIWG-2016-20	Distribute draft primer on Petri plate system calibration by December 2016 (Pescatore)
MIWG-2016-21	Provide liaison copy of draft ISO TR on scene-referred camera output (Walowit)
MIWG-2016-22	Post further images on Medical Photography (Vander Haeghen, Green)
MIWG-2016-23	Review draft guidelines for medical photography (Vogh, Walowit, Holm, Cheydleur, Bai)
MIWG-2016-24	Develop FAQ item for determining display gamut boundary with iccMAX gamutBoundaryDescType (Green)

International Color Consortium

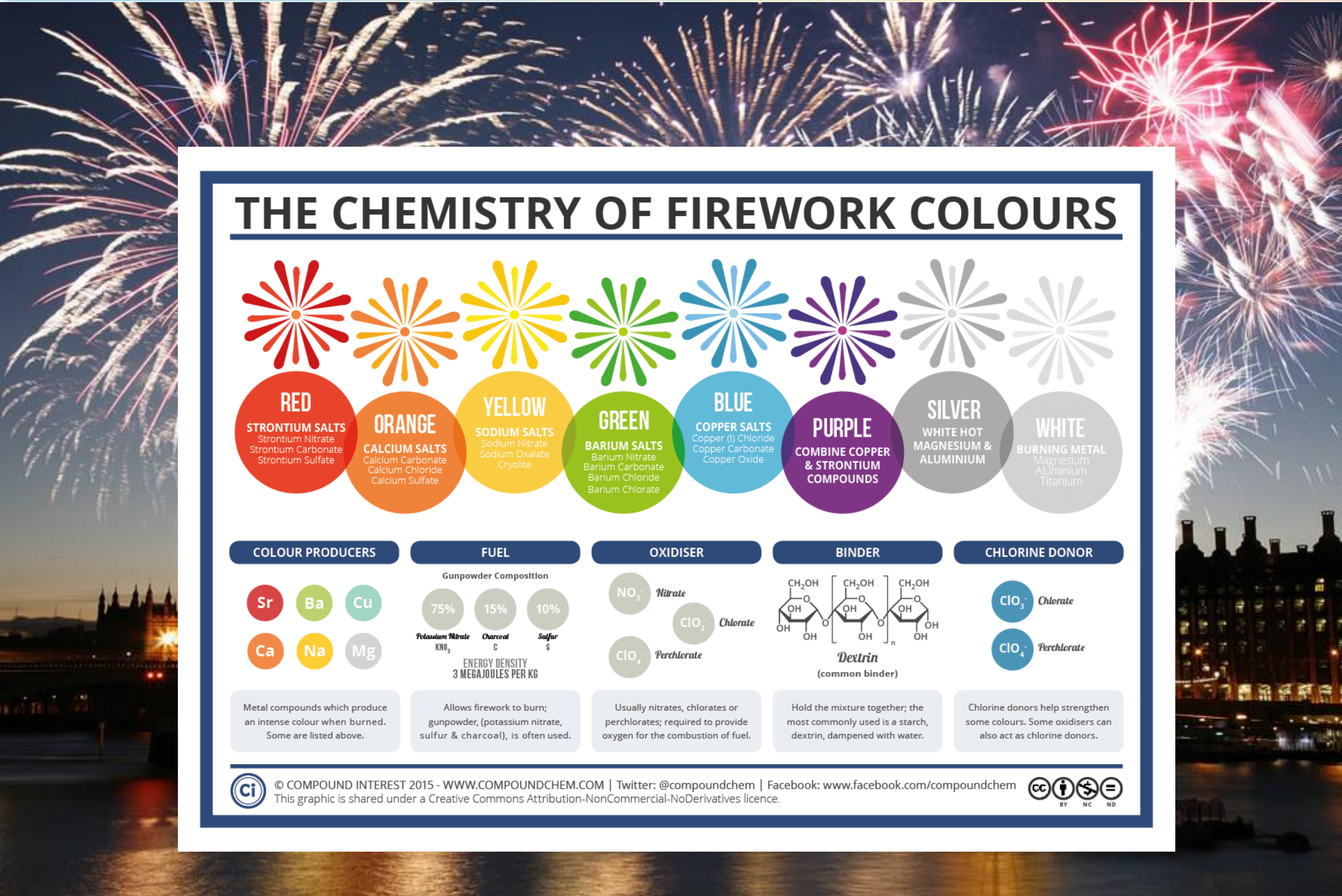
ICC Medical Imaging Working Group

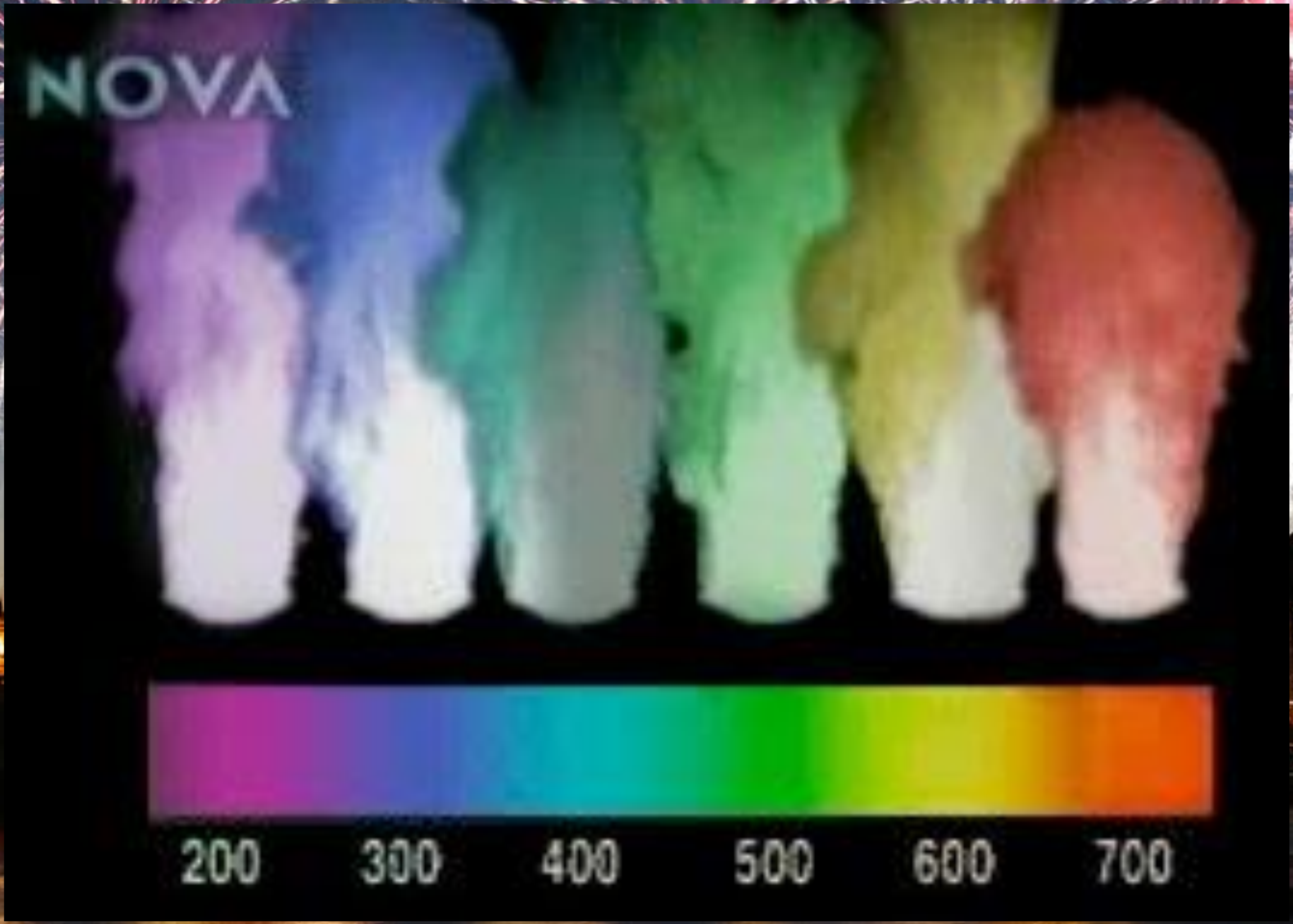
San Diego

5th November 2016

5th November: Guy Fawkes night

International Color Consortium




NOVA
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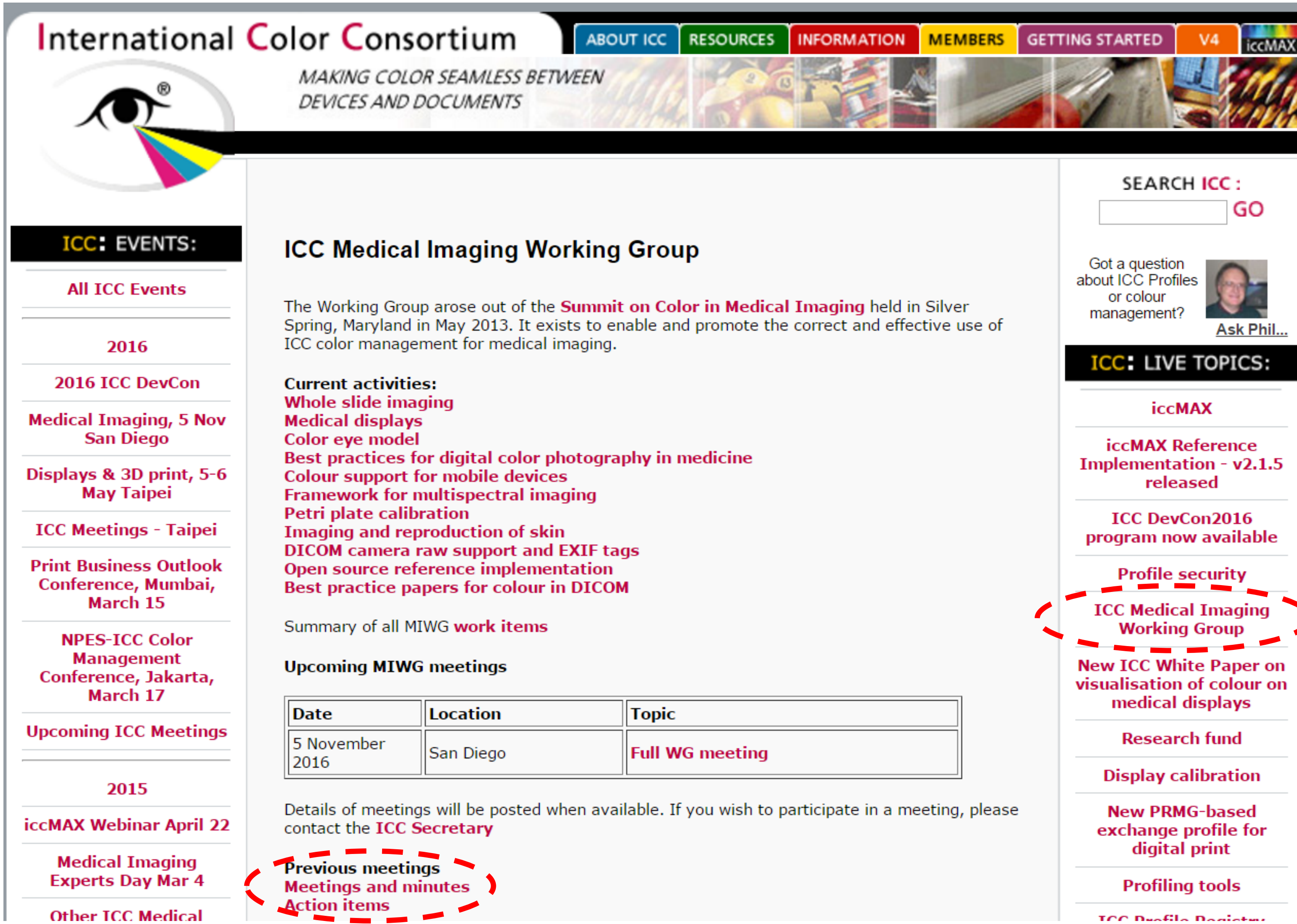
International Color Consortium

iccMAX

ICC MIWG web page at www.color.org



International Color Consortium

ABOUT ICC | RESOURCES | INFORMATION | MEMBERS | GETTING STARTED | V4 | iccMAX

MAKING COLOR SEAMLESS BETWEEN DEVICES AND DOCUMENTS

ICC: EVENTS:

All ICC Events

2016

2016 ICC DevCon

Medical Imaging, 5 Nov San Diego

Displays & 3D print, 5-6 May Taipei

ICC Meetings - Taipei

Print Business Outlook Conference, Mumbai, March 15

NPES-ICC Color Management Conference, Jakarta, March 17

Upcoming ICC Meetings

2015

iccMAX Webinar April 22

Medical Imaging Experts Day Mar 4

Other ICC Medical

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:
- Whole slide imaging
- Medical displays
- 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
5 November 2016	San Diego	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

iccMAX Reference Implementation - v2.1.5 released

ICC DevCon2016 program now available

Profile security

ICC Medical Imaging Working Group

New ICC White Paper on visualisation of colour on medical displays

Research fund

Display calibration

New PRMG-based exchange profile for digital print

Profiling tools

ICC Profile Registry

ICC MIWG Working group meeting

Saturday 5th November, 13:45-16:30

- Introductions
- Colour calibration for Petri dish imaging — Jérémie Pescatore
- Gjøvik masters course on colour in medical imaging — Phil Green
- Updating FAQ 'How do I assess the accuracy of a display profile?‘ — Phil Green
- Medical photography white paper — John Penczek
- How to determine the gamut boundary of a display profile — Phil Green
- Skin imaging update — Kaida Xiao
- Action items review — Craig Revie

Action items review

MIWG-14-16	MIWG	Include recommendation on white surface to be included in scene in medical photography guidelines	03-03-2014	Penczek, Green	Close
MIWG-15-30	Displays	Make assessment targets available to group	13-10-2015	Kimpe	O
MIWG-15-34	WSI	Provide input on calibration errors using different types of training sets	13-10-2015	Holm / Walowit	O
MIWG-16-01	Petri plate	Send Petri plate imaging guidelines for review by MIWG	16-02-2016	Pescatore	Close
MIWG-16-02	Displays	Edit WP44 and circulate for review by end February	16-02-2016	Kimpe / Bai / Revie	Close
MIWG-16-04	Displays	Circulate draft recommendation on display devices for radiology to members	16-02-2016	Revie	Close
MIWG-14-29	Opthalmology	Provide paper on Phase 1 results for publication on ICC web site	19-06-2014	Sisson	O
MIWG-16-07	Photography	Provide further input on medical photography guidelines and workflow figure to Penczek	16-02-2016	Hung	Close
MIWG-16-10	Photography	Provide poster on camera calibration	04-05-2016	Vander Haeghen	Close
MIWG-16-11	Photography	Provide document on camera calibration research project for ICC web site	04-05-2016	Vander Haeghen	O

Action items review (continued)

MIWG-16-12	Displays	Discuss ICS for GSDF and report back to MIWG	04-05-2016	Bai, Derhak, Nagashima-san, Kimpe	O
MIWG-16-13	WSI	Compile list of items for information and guidance for FDA guidance document and post on ICC web site	04-05-2016	Olsen, Vander Haeghen, Chang, Revie, Badano, Green	Close
MIWG-16-05	Displays	Provide comments on draft recommendations on display devices for radiology to Revie	16-02-2016	Martin / Nagashima-san / Bai / Kimpe / Pescatore / Vogh	Close

Microbiology Imaging

Update

MIWG ICC Meeting November 5th 2016

PIONEERING DIAGNOSTICS

Jeremie Pescatore (*Imaging System Design Architect*)

bioMérieux Contributors :

Frederic Pinston & Denis Leroux (innovation unit)

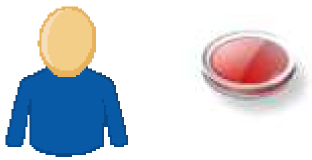
Corine Fulchiron & Delphine Archeny (clinical unit)

Eric Laloum (industry unit)

BIOMÉRIEUX

Background : Virtual Reading versus Manual Reading

Virtual reading **shall be at least equivalent** to manual reading (i.e. : reference method)



? ⇔

Manual Reading = *physically* read an inoculated ppm plate

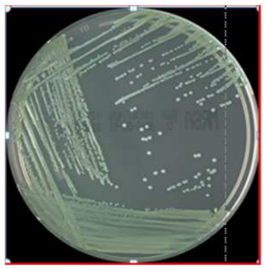
Virtual Reading = reading an inoculated ppm plate on a *display*

Objective : Provide a consistent diagnostic value to petri plate imaging systems

System A

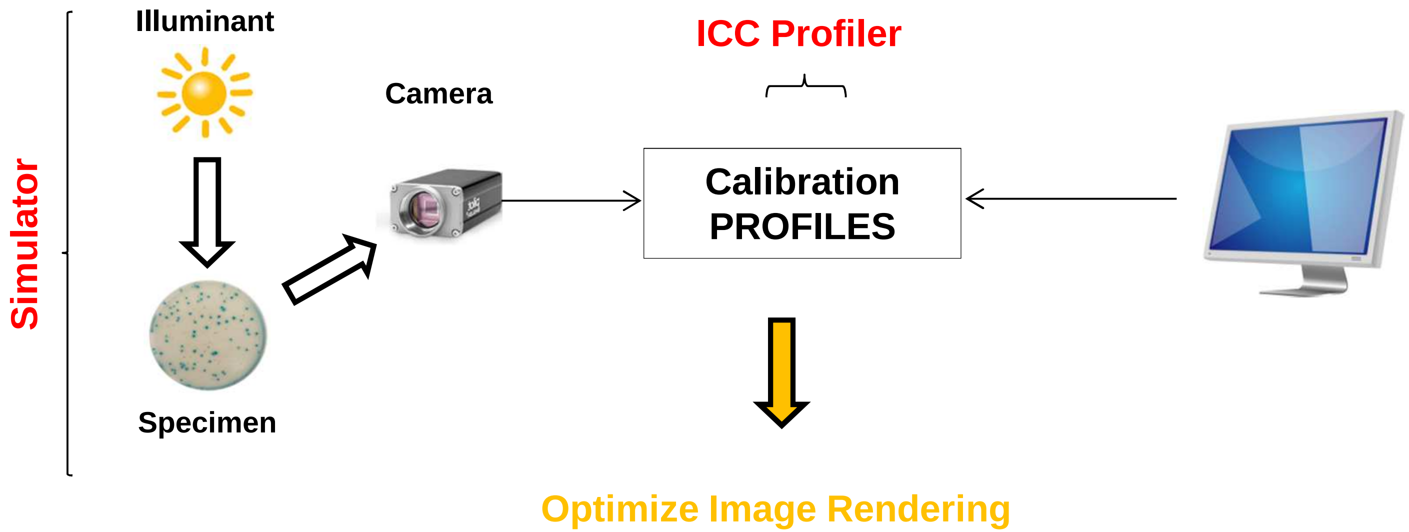
≠

System B



Calibration = Provide consistent rendering

Color Simulator and Calibrator



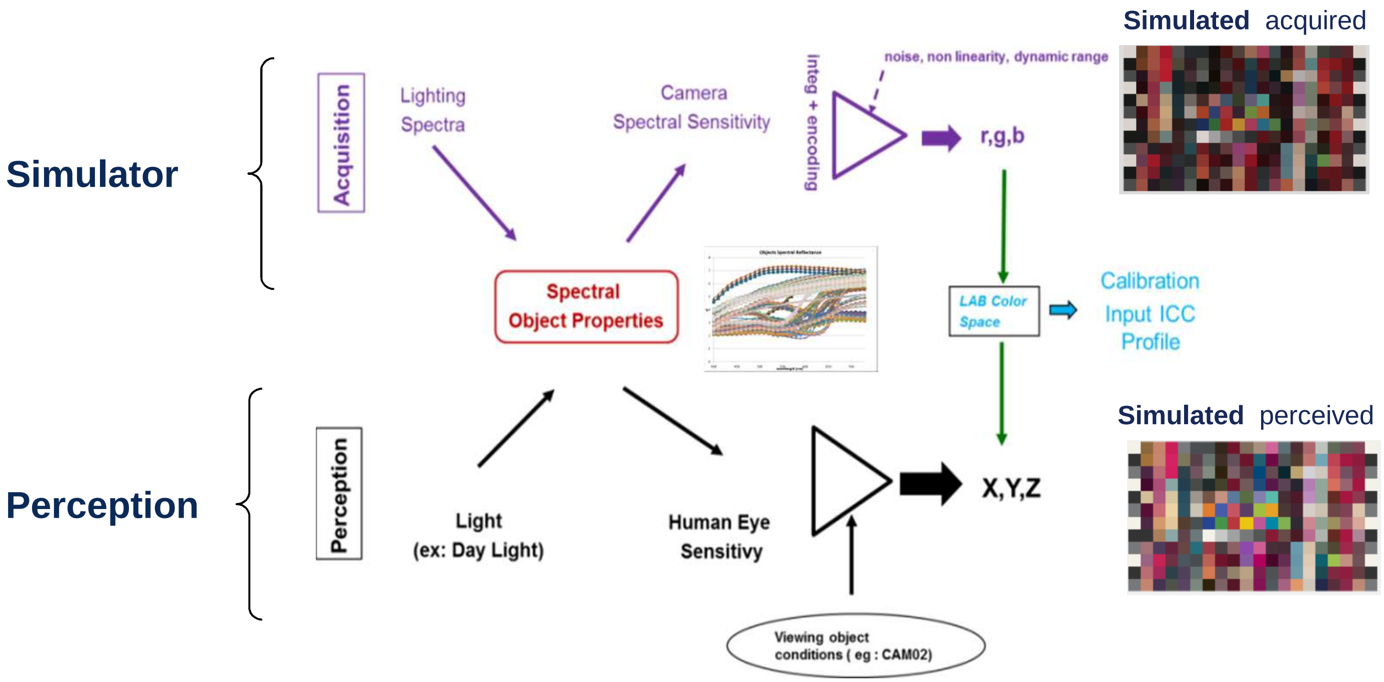
Objectives

Simulator - Develop an image acquisition simulator ➔ spectral reflectance factors to RGB camera conversion

Calibrator – Compute Calibration (i.e. : ICC) profiles from biological samples reflectance

Spectral-Based Color calibration

Based on the spectral knowledge of the biological media and samples



Steps

- RGB values are computed through an image acquisition simulator (spectral reflectance + lightings + camera sensitivity)
- XYZ values are computed through a perception model
- Imaging System Calibration (i.e. ICC) profile

Acquisition System Simulator

Objective: Describe an image acquisition simulator that predicts the digital values computed by a real camera

• Inputs

- Object spectral **reflectance** (spectral biological data)
- **Illuminant** spectral power (LEDs or standard illuminant)
- Spectral **sensitivity** of the camera sensor

• Output

- RGB image of the scene

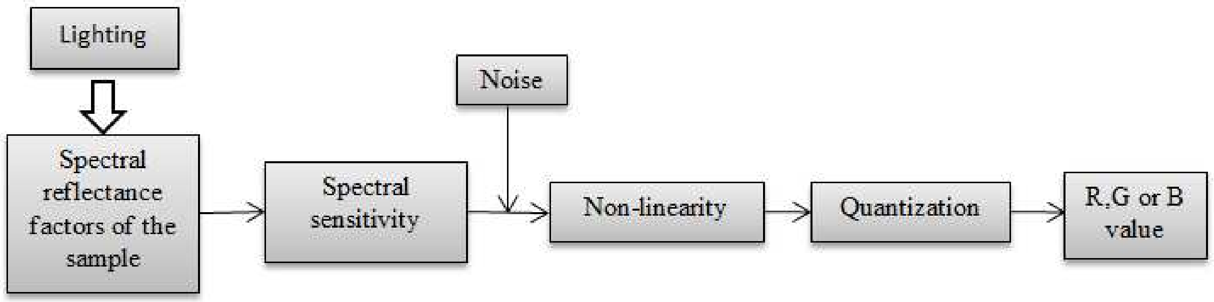
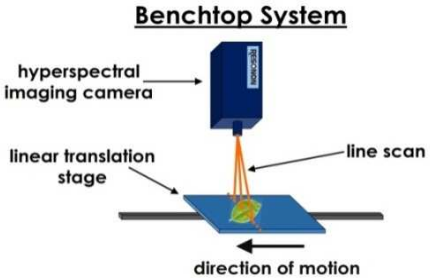
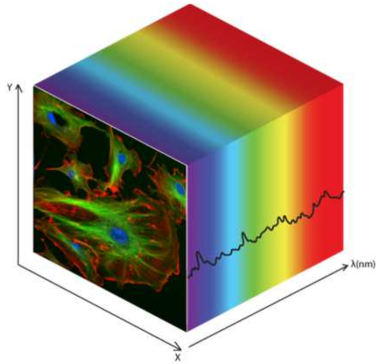
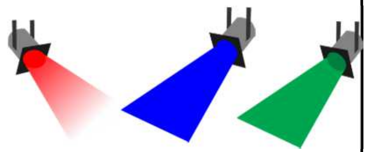


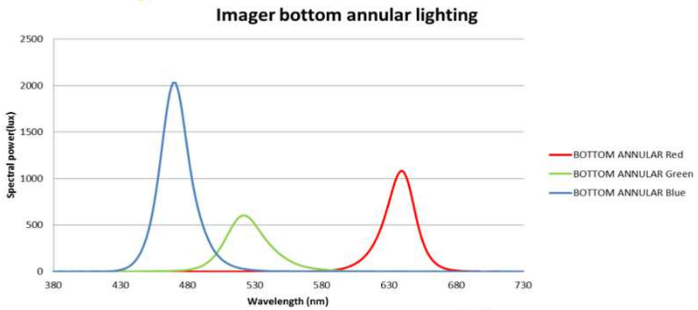
Image acquisition chain

➢ Develop a mathematical model

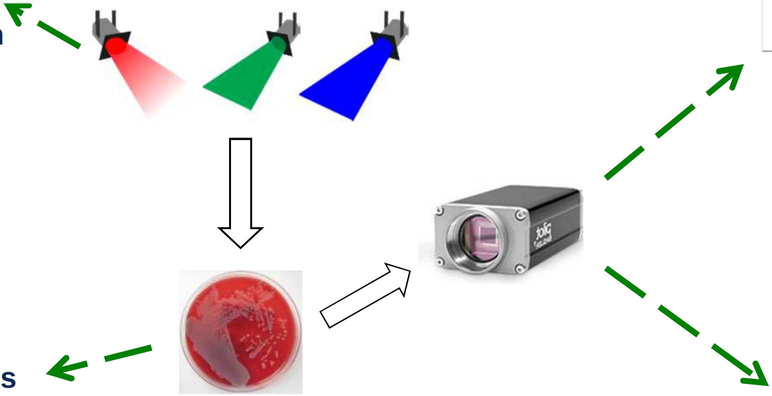
Simulator – Measurement devices

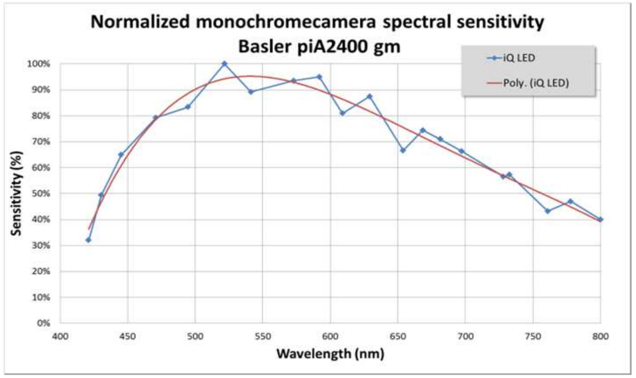
Spectral reflectance factors	Camera spectral sensitivities	Illuminant spectral power	Noise measurement
  Hyperspectral cube	 IQ Led (14 bands) Sampling ~  Monochromator sampling ~ 10 nm	  Spectrometer	 Black mask in front of the camera lens

Simulator – Measures



Spectral power distribution

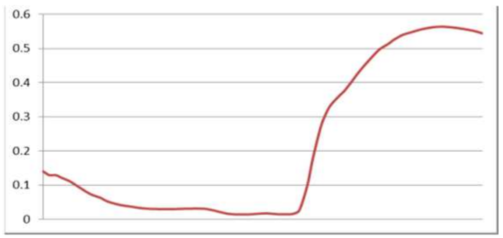




Sensitivity measures

- Measure the spectral power of **incident** lighting
- Compute the related sensitivity (sensor + lens)

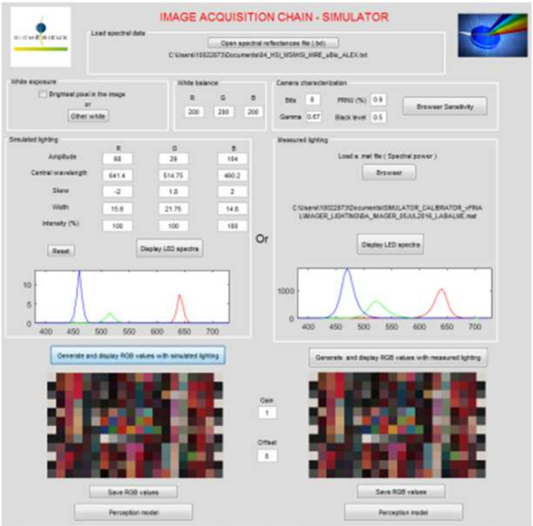
Spectral reflectance factors



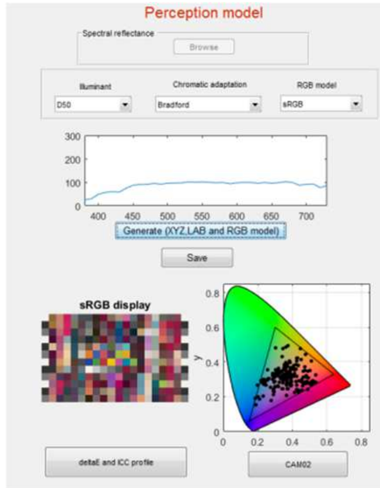
Noise measures

Color calibration matlab tool

Simulator
RGB values

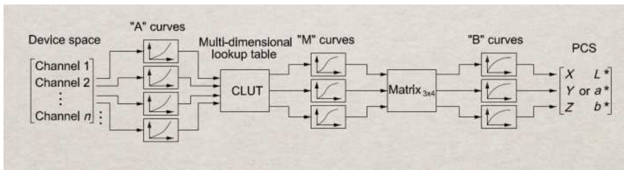


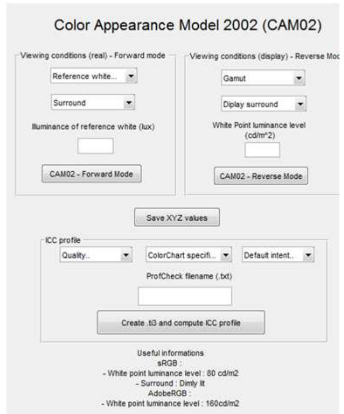
Perception model
XYZ or LAB values



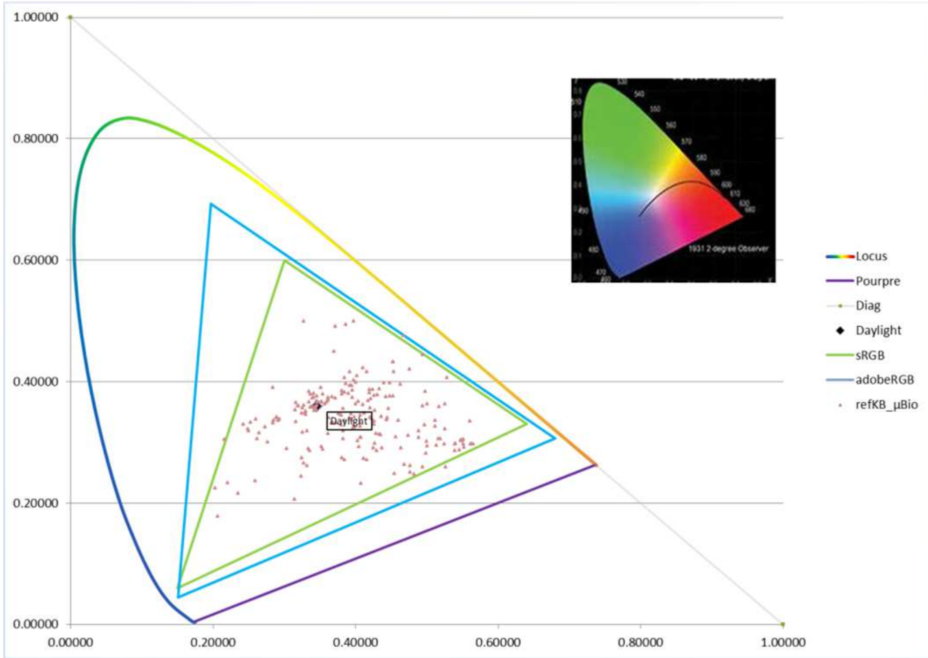
Transformation tables

Input ICC profiles (using ArgyllCMS)



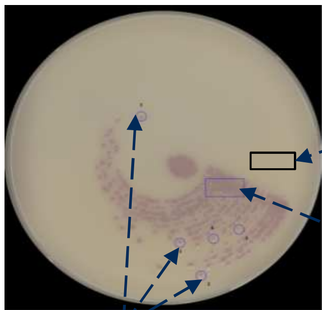


Reference KB µBIO - Content



4 Different Region Interest

- AGAR
- COLORED AGAR
- MASS
- ISOLATES



Background = AGAR or COLORED AGAR

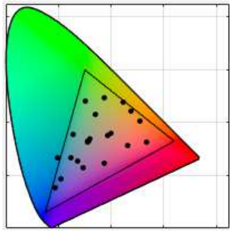
Mass

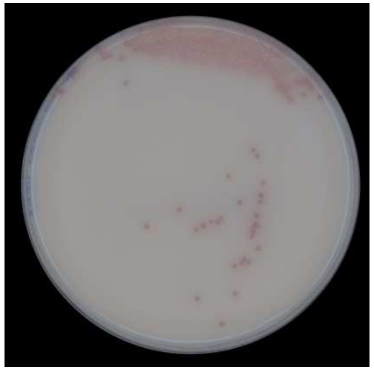
Isolates

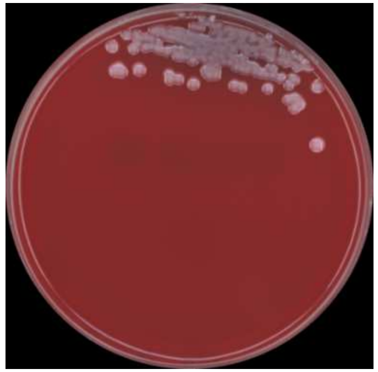
➔ 20 different bioMerieux culture media were used.

Color calibration - Results

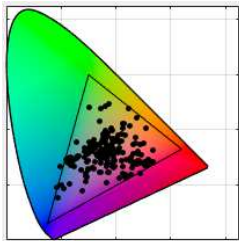
ColorChecker (24)

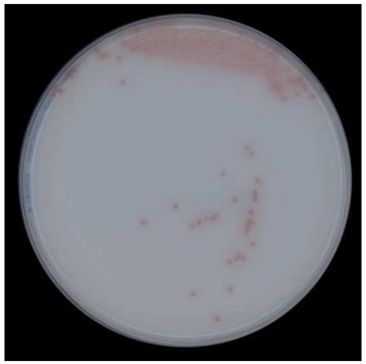


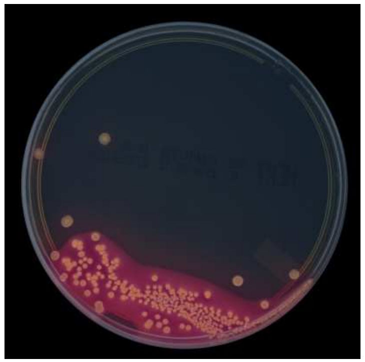




Microbiological knowledge (240)







2016 Achievements

We have developed numerous tools :

✓An image acquisition simulator (monochrome and color camera)
✓A tool which computes XYZ and LAB tri-stimulus values (and many other colorimetric functions)
✓A tool which computes ICC profiles without using any commercial tool
✓A tool which uses the Color Appearance Model 02 (CAM02)
✓Graphical user interfaces

Results

- The imaging simulator is **validated** for a **ΔE < 2** compared to real images (for **non-transparent** objects)

- Hyperspectral imaging system provides **adequate** agar reflectance factor measurements

- The calibration (i.e. : ICC) profiles generated with the spectral-based method is **equivalent** to chart based method when a ColorChecker is used.

- The profile computed with a microbiological spectral knowledge base seems to give **better rendering results** especially for blood medium.

Next Steps

- **Decision to split the exiting document into 1 primer & 3 white papers**
- **1 x primer on microbiological imaging ➔ late**
- **3 white papers :**
  - WPA - Spectral Characterization - Acquisition – Analysis

  ➔ **Open Point** : for non transparent objects, special methods might ***need to be IP protected*** before publishing.

  - WPB - Spectral Knowledge Base

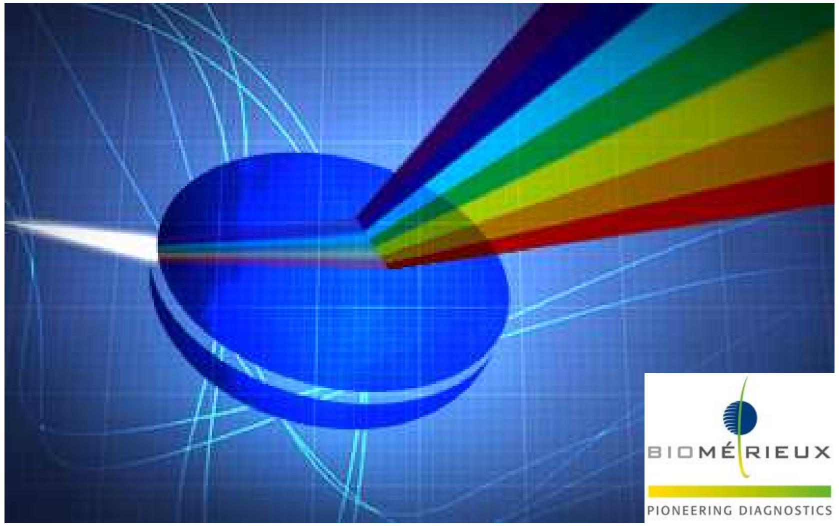
  ➔ **Open Point:** How to share the virtual target content with the MIWG ?

  - WPC - Spectral Calibration

  ➔ **Open Point** : investigate how the calibration matlab tool good be shared or not within the MIWG ?

➔ **The plan** is to have an **internal** clinical evaluation of the spectral based calibration.

Thank you



Jeremie.pescatore@biomerieux.com

International Color Consortium

Colour in Science and Industry

San Diego

4 November 2016

Colour in Science and Industry

- Two-year Master degree in EU Erasmus Mundi programme
- Programme shared between colour science and imaging departments in France, Spain, Norway and Finland
- Attractive student funding – full bursaries – leads to high numbers of applicants and rigorous selection process
- Students have 6 months each in St Etienne (France) and Granada (Spain), 6 months in Gjovik (Norway) or Joenssu (Finland), and 6 months working on a Master Thesis project

COSI Applied Colour Science track

Delivered in Norway in Semester 3 (September – December)

Includes course on Colour in Medical Imaging

Focuses on calibration of medical imaging systems

Topics include:

- Medical photography
- Skin imaging
- Calibration of input devices
- Calibration of displays

Medical Imaging coursework project

Coursework project is how course is assessed

Students develop project brief that relates to their interests and background

Current projects:

- Methods to measure scattering in skin
- Spectral unmixing
- Illumination in clinical photography
- Procedures for RAW in clinical photography

Future projects

Projects in collaboration with vendors and institutions in medical field welcome

2017:

coursework projects (September to December semester)

- c. 100hrs work

Master Thesis project (January to June)

- c. 600 hours work
- Can be on-site

Improving Color Image Quality in Medicine Photography

J. Penczek, Y. Vander Haeghen, E. Krupinski, P. Green, and P. A. Boynton

1 Nov., 2016

Abstract:
Color images are becoming an increasingly popular means for capturing, diagnosing, and recording medical information. In medical photography, the intent is often to create images that accurately represent the subject colors. This report summarizes digital photography best practices and provides guidance for creating an image workflow that strives to accurately render the consistent scene colors.

Introduction:[Penczek, Krupinski]
Medical images have played an important role in the development of modern medicine. They have provided a valuable means for capturing, storing, transmitting and viewing complex visual information. The introduction of digital detectors and display devices in areas such as radiography has made the communication and analysis of the most common of these images easier compared to hard copy film based images. Dedicated monitor specifications and display calibration tools (e.g. the Digital Imaging and Communications in Medicine Grayscale Standard Display Function, DICOM GSDF) were developed to ensure accurate and reproducible presentation of these grayscale images across different monitors to ensure that diagnostic accuracy would not be impacted by differences between displays [1]. Although radiology images sometimes use pseudo-color to enhance specific diagnostic features (e.g., blood flow in Doppler ultrasound), there are no inherently color images in radiology.

The prevalence of inexpensive color digital cameras, however, has dramatically increased the use of color images in other areas of medicine. The growth of telemedicine has further enhanced the utility of these medical records. Clinical specialties such as dermatology, ophthalmology, surgery, pathology, and gastroenterology regularly use visible light images in their practices. Increasingly a host of new imaging tools that acquire and display color images are being incorporated into clinical practice (e.g., fiber-optic based imaging tools to assess ovarian cancer).

The human visual system (HVS) is very effective in recognizing critical features by processing visual attributes such as brightness and color variations in an image. The medical industry has recognized the dependence of the HVS on the relative brightness of image features, and has implemented the DICOM GSDF standard to achieve a perceptually uniform scale for critical grayscale imagery [1]. However, this standard does not address color images. Several groups are currently developing proposals to introduce a medical color imaging process that is compatible with DICOM [2,3].

The color image processing methods and tools can differ depending on the intent of the content and/or the task of the viewer. In some cases (like false color maps in radiology), the need for accurate color reproduction may not be important since the actual colors have no representation of the real world, but are merely used to highlight additional information that is related to the image. In fields like dermatology and pathology, the image colors provide valuable information that should be properly displayed to the final viewer so they can render the most accurate diagnosis possible. This article addresses the needs of the latter case, and provides guidance to medical color image users for achieving the best possible color reproduction on a digital display.

Modern digital color image workflows can be generically described as illustrated in Figure 1. A more detailed description can be obtained in recent digital camera standards [4,5]. A digital camera captures the scene in a proprietary format and applies corrections to the image that are specific to the camera. The accuracy of the color information captured on the sensor can be affected by factors such as the ambient lightings, the lens design, and the sensor technology. In simple point-and-shoot cameras, the camera will usually store the color image in standard compressed formats like JPEG and TIFF. These compressed formats often include image enhancements encoded into the data, and the colors are normally transformed to be viewed in a standard output-referred color space (such as sRGB) [6]. This process is illustrated in the top section of Figure 1. The bottom section gives possible color correction pathways.

The sRGB color space is typically used as the standard color space in digital camera image encoding since it is expected that the images will likely be viewed on a display that is calibrated for that color space (although that is rarely the case in medicine). Digital single-lens reflex (DSLR) cameras tend to give the user more control over how the color data is processed and formatted. The DSLRs usually offer the user the ability to store the image data in a proprietary RAW format, which is uncompressed, has larger grayscale resolution (bit-depth), and includes minimal image enhancements applied to the original data. Since image enhancements can make it more difficult to color-correct an image in post-processing, the RAW format can have some advantages. The camera manufacturer’s RAW file format is generally specific to the manufacturer, and usually requires the manufacturer’s software to view the image properly. However, some third party companies have RAW image converters/decoders that are able to extract the image data from the RAW image files and transform them into a common format (such as DNG) that preserves much of the image information [7].

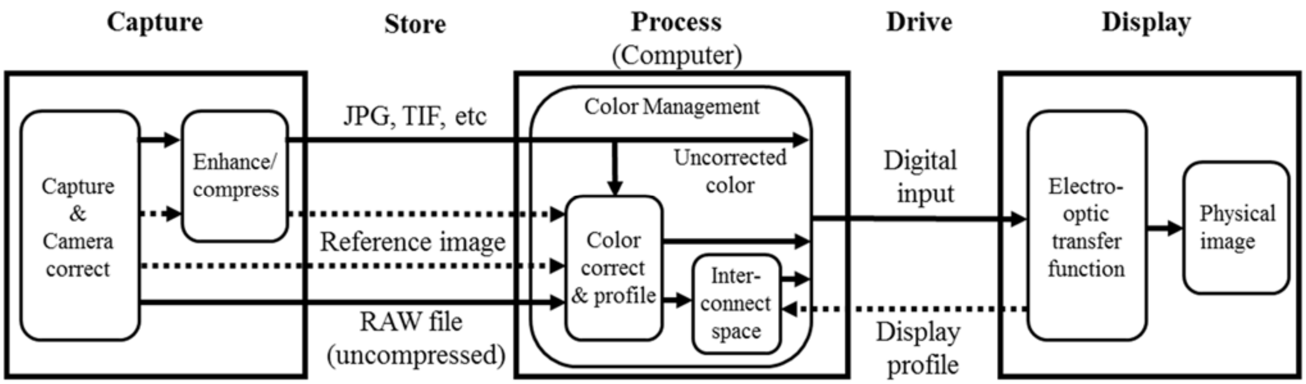


Figure 1: Functional flow diagram of a generic digital color image process, from image capture to its display. The concept of the reference image is used for workflows were color correction are applied.

Before an image file can be viewed, it must be processed by a computer and rendered properly on a display. In the simplest case, the image processing software recognizes the compressed (or uncompressed as the case may be) file format and directly drives the display input. If the display was calibrated to the same color space as the encoded image data (e.g. sRGB), then there is a chance that the scene colors will be rendered properly to the viewer. However, as we will discuss later, directly rendering images without color-correcting can yield significant color errors. Fortunately, the accuracy and reliability of the color images can be significantly improved by employing methods used by professional photographers. It is common practice to place a reference color chart (e.g. Macbeth color chart), with well-characterized colors, in the same scene as the object to be photographed [8,9]. The digital images of the reference color chart taken under the same conditions as the intended object of interest can be compared and used to color-correct the object image data. The color correction can be implemented by directly creating a new image file with the corrected color data transformed to a standard color space (e.g. sRGB) for later viewing.

Alternatively, the necessary transformation needed to color-correct the original object image can be saved separately as a color preset or profile. This preset or profile must then be applied to the original image prior to being rendered by the display. This open-loop process can work for a fixed image capture and display viewing environment, which is difficult to obtain in a clinical context. However, a more flexible closed-loop process can also be utilized using the open source ICC profile methodology [10]. The ICC framework uses a virtual interconnection color space that transforms the color-corrected image to the proper color space used by the output device, either printer or display.

Given the above background information on digital camera color image processing, we will further highlight the factors that contribute to color errors, discuss proper camera and lighting setups for improved color reproduction, review the use of color charts, and dive deeper into the color correction processing. In addition, a summation of our findings is given in terms of a recommended procedure, which describes the industry best practice for improving the rendered color accuracy.

Factors that contribute to color error:[Penczek, Krupinski, Vander Haeghen, Boynton]
As suggested in Figure 1, the image colors viewed on the display can be affected by the actual image capture setup, the image processing, and the physical rendering on the display. Recent research compared the relative contributions of the image color error produced by a point-and-shoot camera, the gamut mapping of the color management system, and the error measured from the display with a factory calibration [11]. The study found that the color errors introduced by the camera capture process were dominant. In addition, since the image capture was at the beginning of the workflow, these color errors would propagate and likely be enhanced by the other error sources. Therefore, taking precautions to improve the image capture process will have the greatest benefit toward minimizing the final color errors viewed on the display. Toward that end, we first identify the factors in the image capture process that produce the most significant color errors.

Lighting uniformity- An important factor that can impact overall image quality as well as color, is the part of the body being imaged. A full body skin scan is feasible, but it may not always show all skin lesions and surfaces with sufficient detail. Enhanced lighting, multiple images and several angles may be helpful. The scalp and other areas with a significant amount of hair may need to have the hair physically displaced or removed, and special lighting may enhance viewing conditions. Mucosal lesions and orifices, including genitalia, often require special attention to lighting and exposure in order to allow examination, especially with respect to reflections off shiny, moist tissues that could impact the colors rendered. The color of the patient's skin itself in combination with the lighting and background conditions may change the color of photographed skin lesions. Therefore, the quality of lighting on the subject area is critical. Directional lighting may be useful to reviewed texture, depth, and morphology. However, this can lead to glare and non-uniform illumination over the image. It has been shown that non-uniform lighting can strongly influence the resulting color error in the image [12].

Spectrum of lighting- The surface color we perceive is dependent on the spectrum of light illuminating the surface. Therefore, if the illumination spectrum is not the same for each camera capture session, or the spectrum changes over time, then it will be more difficult to compare the colors in images taken under those different illumination spectra. In some cases, the photographer can allow the camera to adapt to a common white point spectrum, but this is often not sufficient. Previous work has shown that the ability of a camera to adapt a changeable spectrum to a desired white point depends on the camera technology and the spectrum of the light [13]. The performance tends to be best when the light spectrum is close to the desired white point for viewing.

Camera technology- One would expect that the quality of the images would be dependent on the camera technology. In many cases, the color errors can be reduced by using more complex camera technology, for example using a digital single-lens reflex (SLR) camera instead of a cell phone camera [13]. However, the trend may not always be consistent. For example, a cell phone camera can have smaller color errors for flesh tones illuminated by incandescent light than a digital SLR. In addition, a camera that has the largest median color error for a given set of colors may not necessarily produce the largest maximum color errors for those colors [12].

Subject color- The camera color error generally depends on the color to be imaged. Although some studies have shown that more saturated colors (like red and blue) tend to have larger color errors, flesh tones can also produce substantial color errors [13]. The HVS is especially sensitive to memory colors, like flesh tones. A study on artificial skin found that CIELAB color differences of ΔE^*_{ab}=1.1 were perceptible and ΔE^*_{ab}=3.0 were at the acceptability threshold for light specimens, and ΔE^*_{ab}=1.6 were perceptible and ΔE^*_{ab}=4.4 were at the acceptability threshold for dark specimens [14,15]. This color difference values provide useful guidelines for the amount of color errors that may be tolerable for medical photography.

In addition to the above-mentioned factors, standard photography best practices require that the region of interest that is imaged be properly focused, framed, and have the proper exposure (not over or under-exposed). Figure 2 illustrate some common examples of poor photography technique, some of which can affect the color quality of the image. The top left image has bad white balance, the top right was over-exposed, the bottom left suffers from non-uniform lighting, and bottom right has improper focal depth.

Figure 2: Common examples of poor photography technique.

Achieving consistent color:[Penczek, Krupinski, Vander Haeghen]
Prior to offering recommendations on how the image color quality can be improved, we first put forth a set of operational use objectives for the medical photography workflow. The objectives emphasize the need for consistent color reproduction for the evaluation of medical images.

1	Visually inspecting a region of interest in a single image in a consistent manner
2	Measuring properties of certain areas in a region of interest of an image in a consistent manner
3	Visually comparing regions of interests in one or several images in a consistent manner
4	Comparing measurements of certain areas in regions of interest in one or several images in a consistent manner.

Table 1: Main operational use objectives for medical photography.

This is not an exhaustive list, but many other tasks and objectives can be automatically enabled by these 4 items (e.g. good documentation and record keeping, follow-up over long periods, telemedicine, teaching, etc…). The term 'consistent' is admittedly vague and needs to be clarified for a specific application. From the perspective of maintaining the image color integrity, this article strives for color consistency by avoiding or eliminating any factors that can change the perceived color of a patient's image which could affect the interpretation of that image. Although the perceived image color can be affected by the display system and the viewing environment used to view the display, our discussions are limited to the impact of the image capture process and any subsequent color corrections.

In practice, the color inconsistency caused by lighting variability when taking images of the same patient's body part over time can make it difficult to gauge the evolution of the medical condition seen in the images. The same can be said when using different cameras, changing camera settings, different lighting geometry, etc... The severity and impact of those confounding factors can obviously be very variable and highly dependent on the patient's body part and medical condition. This is illustrated by the examples shown in Fig. 3. For the images of the patient in the top row of Fig. 3, it is not completely clear whether the patient's skin has changed, or that the camera setting and lighting are different. In this case, the patient's skin has indeed changed, but not nearly as much as would be suggested by the image. The background grays are different for each image, which makes it difficult to assess the relative amount of change. The bottom images in Fig. 3 show the case of atypical nevi for skin cancer detection. Not only does the variance in the photography technique between images make it difficult to monitor the change in the cancer, but it is even difficult to know what is the real skin phototype of the patient.

Color is very important, and this places high demands on the consistency of colors in the acquired images. Similarly, when evaluating ulcers, the measured area of an ulcer can be important, and thus the physical resolution in the region of interest must be known so that areas can be consistently compared. It should be noted that consistency does not necessarily mean faithfulness. It is possible to be consistent, and thus comparable, without being an exact copy of how the scene looked to the photographer during acquisition. For example, image colors can be modified to represent the scene under a certain predefined and fixed light source.

In general, the colors rendered to the viewer are typically either scene-referred or output-referred. The purpose of scene-referred rendering is to accurately duplicate the original scene. In contrast, output-referred rendering tries to align the image colors to the output device (the display or printer).

Figure 3: Examples of possible confusion due to photography. The images in each row are of the same patient.

In order to enhance the quality and utility of medical photography, it is valuable to ensure colors are rendered in a standard way, irrespective of the lighting environment when the image was acquired. This enables all the objectives that involve comparisons (items 2-4 in Table 1), and it usually also makes inspections easier (item 1). One way to achieve this would be to use exactly the same standard set of conditions during the image acquisition (lighting, exposure, calibrated camera, geometry, etc...). This is very restrictive and nearly impossible in practice.

Another way of achieving this is by using standard hardware (like consumer cameras), and by calibrating the image to a standard set of conditions after the acquisition. This typically involves adding some kind of color chart with known colorimetric properties in the scene during acquisition. In addition, the color chart can also serve as a scale marker, allowing the accurate determination of dimensions for areas in the imaging plane of the chart.

One of the most important and often challenging factors in ensuring proper photography and consistent color data is inhomogeneous lighting (see Fig. 2, bottom left). It is clear that if the lighting over a region of interest is uneven, it will be very difficult to obtain sensible color measurements from it, and no amount of calibration is going to help. For accurate color images, uniform diffuse lighting tends to work best. Some examples of diffuse lighting setups are shown in Figure 4. But even with a uniform light source, lighting can still be uneven if the object geometry is not considered (oblique angles, shadows, etc...). It is best to ensure that the region of interest is nominally perpendicular to the optical axis (the line going straight from the camera sensor through the lens to the scene). Clearly this can be quite challenging if the region of interest is not flat (see Fig. 5, middle image in the bottom). Also with wet or moist areas in the region of interest this can lead to specular (mirror-like) reflections, visible as very bright white regions (see also left image in Fig. 5). Normal flash photography tends to make this problem worse, although a special ring-like flash for close-up photography may alleviate this because the incoming light from the flash is coming from the sides. When present, specular reflections can usually be diminished by angling the light source away from the optical axis. Figure 5 also provides a good demonstration of how the white point can be changed through proper color correction. An illustrated guide for medical photography (with color chart) is given in Fig. 6.

Figure 4: Example of diffuse lighting setups using commercial softbox lighting (left), or a homemade lightbox with diffuse walls (right).

Figure 5: Color calibration using a color chart. Top row shows the uncalibrated images, and the bottom row the corresponding images calibrated to a CIE D65 white point. Images courtesy of Dr. S. Van Poucke and Prof. Dr. H. Beele.

Figure 6: Illustrated photography guidelines. Top row: good image, image with uneven lighting. Second row: chart not in the same region of interest (toy house). Third row: chart not in view, poor framing (too small). Fourth row: over-exposed and under-exposed image. Bottom row: scene not perpendicular to optical axis, and chart is angled.

As mentioned previously, a good approach to achieving consistent colors is to calibrate the image to a standard set of conditions after the acquisition. We refer to this as standard output-referred rendering. An important aspect of this is to standardize the white point of the calibrated image. CIE D65 simulates a daylight spectrum with a white point that is commonly used in digital photography and display technology, and would serve as an obvious standard white point [6,14]. Although it is difficult to accurately realize the D65 spectrum in practice, the color calibration to this idealized spectrum will be better if the actual light source used during the image capture at least approximates this spectrum [13]. Dedicated full spectrum light sources are normally better (see Fig.4) at approximating daylight than the flash built into the cameras.

Another factor that can help achieve color consistency is the quality of the camera technology. Many advanced cameras can have the ability to choose a white point that more accurately represents the actual scene, which can be helpful in the subsequent calibration process. These cameras tend to also support the use of RAW image formats. Using raw camera data instead of the more traditional JPEG workflow will increase the quality of the final color corrected images because this avoids a lot of the non-linear image processing often used to perceptually enhance the image. The higher bit-depth and dynamic range of raw camera data also avoids problems with data saturation (values at the minimum or the maximum of the possible range) due to poor exposure settings or light sources that are very yellow or bluish.

In addition to the more technical aspect of the image capture process, color consistency can in general be improved by using good photography practices. This includes removing distracting jewelry and clothing prior to acquiring the images, as they are distracting visually but could also overlap lesions and potentially distort colors. Although using flash lighting can sometimes eliminate shadows, it can cause white out and distort the colors. Uniform diffuse lighting is generally preferred for color consistency.

Color correction:[Vander Haeghen, Penczek]
For color consistency, our goal for color correction display the imaged scene as it would have looked like under a standard light source, such as CIE D65. We describe this as standard output-referred, as opposed to scene-referred which tries to create a faithful reproduction of the scene. Although this may result in an image that looks different than how it appeared in the original scene, the benefits of doing so far outweigh this downside. The viewing and colorimetric measurements of standard output-referred images will be more consistent over time. This enables qualitative (visual) and quantitative (physical measurements) comparisons to be made, and is more forgiving of different setups. And by using a standard CIE D65 white point, it is easier to render the images on commercial displays.

The color calibration will typically transform the image to a standard color space called sRGB (output-referred rendering), or provide an ICC input profile to implement this [6]. Since sRGB tends to be the native color space of modern displays, this output-rendered image will display correctly without any further assistance. For calibrated displays or printers that have an ICC output profile, output more accurate color rendering is possible. The same is true when the acquired image has a sRGB input ICC profile associated with it, with the added benefit of not having modified the original image data.

As mentioned previously, in order to correct the original image colors to what they should be in a standard lighting environment (such as sRGB), professional photographers normally use a reference color chart. The color chart can be placed side-by-side with the region to be imaged, or it may be imaged before or after the photography session. In the latter case, care must be taken to replicate the same placement and lighting/camera conditions. The image data from the reference color chart can then be used to transform the patient image to standard output-referred colors. Commercial software is available to perform this color correction, with varying results [13]. The flowchart in Fig. 7 highlights the main components of the color correction process. The number of stars are the bottom of the figure give a rough indication of the quality of the final displayed image with respect to the objectives outlined in Table 1. Usually the quality of the results increase further if RAW camera data is used instead of the typical JPEG images. This is indicated by the extra red star. A more detailed flowchart of the color correction process, with the color chart in a side-by-side or sequential procedure, is given in Appendix A. A detailed recommended color image capture and color correction procedure is also given in Appendix B.

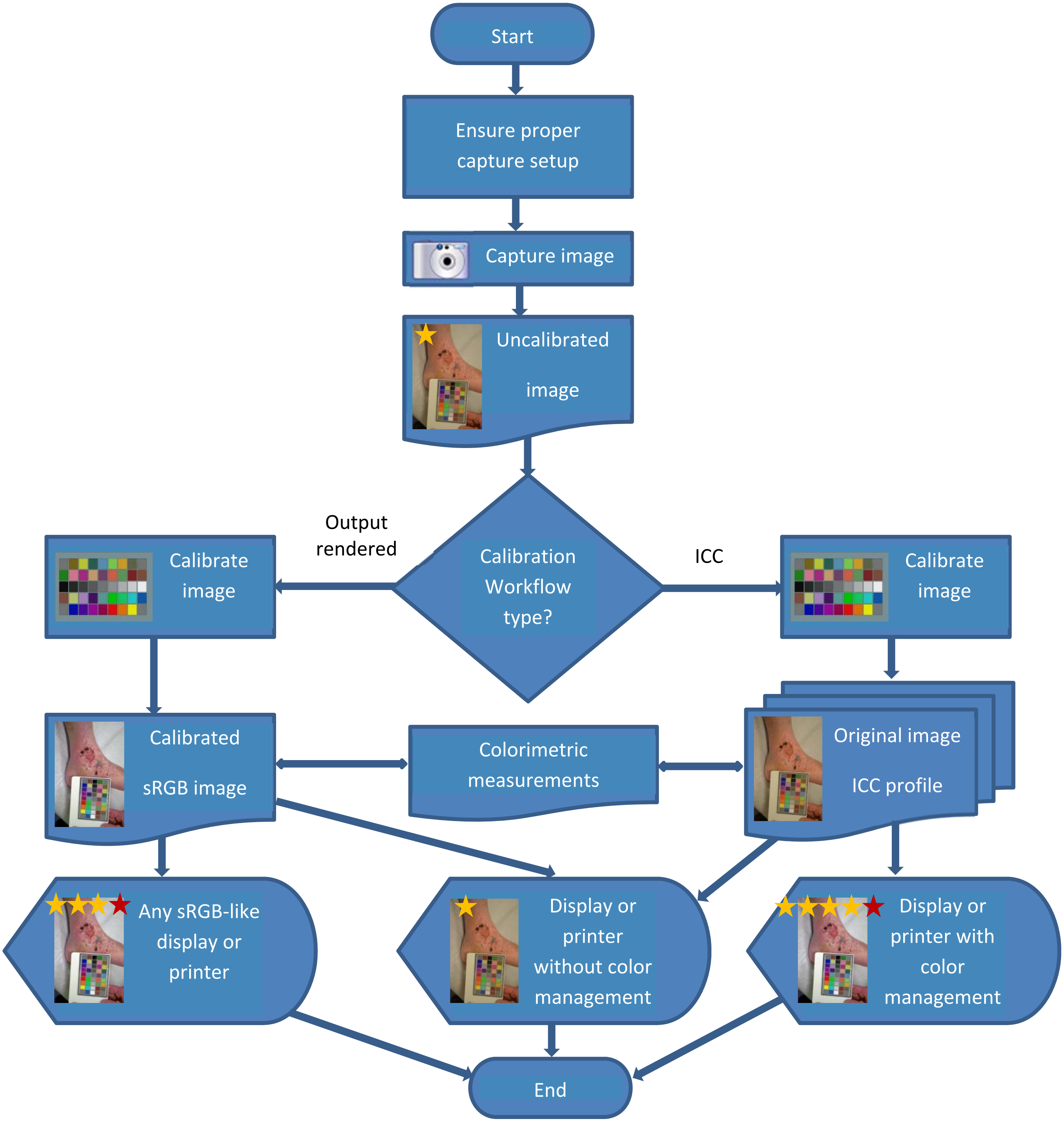


Figure 7: Functional flow diagram of the color correction process, with either direct output-referred rendering or the use of ICC profiles.

General color management considerations:[Green]
ICC color management provides a basis for consistently communicating the color of the original image throughout subsequent operations of display, archiving and reproduction. The ICC architecture, first published in 1994, is used in most color imaging tasks, especially in professional workflows in photography and graphic arts.

As indicated in the previous section, it is recommended that medical images are converted to an output referred color encoding. sRGB is the most widely used encoding for this purpose, and medical photography subject matter will normally fall within the color gamut of sRGB. In situations where images are to be printed commercially or displayed on extended-gamut monitors, it may be necessary to convert to a different encoding such as Adobe RGB (1998).

In many simple workflows, especially those used in consumer applications, it is assumed that images are to be interpreted as being encoded and displayed in sRGB, in which case no conversions are required and although it is always recommended to embed the source profile it may not be essential. However, where an image may have a range of purposes, it is recommended that the profile which represents the output-referred state of the image (most often sRGB) is embedded by assigning this profile before saving the image. Subsequently it may be required to convert the image so that the same colors are reproduced in a different color encoding. In this case the image is converted using the embedded profile as source, the required output color encoding as destination, and the Media-Relative Colorimetric rendering intent to ensure that color fidelity is preserved relative to the media white.

Conclusion:[Penczek]
Research has shown that a typical image capture workflow for medical photography can yield significant color errors compared to acceptability thresholds for skin tones [13,15]. The simpler camera technologies, non-uniform lighting and an illumination spectrum that substantially differs from daylight are key factors that contribute to the color errors. These factors can be minimized by the proper implementation of camera technology, and using uniform diffuse illumination that approximates the daylight spectrum. Further improvements in color accuracy can be achieved by applying color corrections methods developed for professional photography, which utilize color reference charts. In developing a medical photography workflow with color correction, we submit that there is great value in emphasizing color consistency between image capture events. By color correcting images to a standard CIE D65 white point, the viewer can more easily compare the evolution of color images rendered on common displays. Detailed workflows and procedures are proposed that realize the concept of standard output-referred rendering for achieving color consistency. If the full guidelines cannot be followed, then a basic set of steps is recommended in Appendix D to help achieve a minimal level of color consistency. The implementation of these procedures and workflows is best executed through closed-loop color-managed systems utilizing color profiles, such as ICC profiles. The application of these color correction methods are expected to improve diagnostic search times and outcomes. However, greater automation of these methods is needed in order to obtain greater acceptance within the medical community [26].

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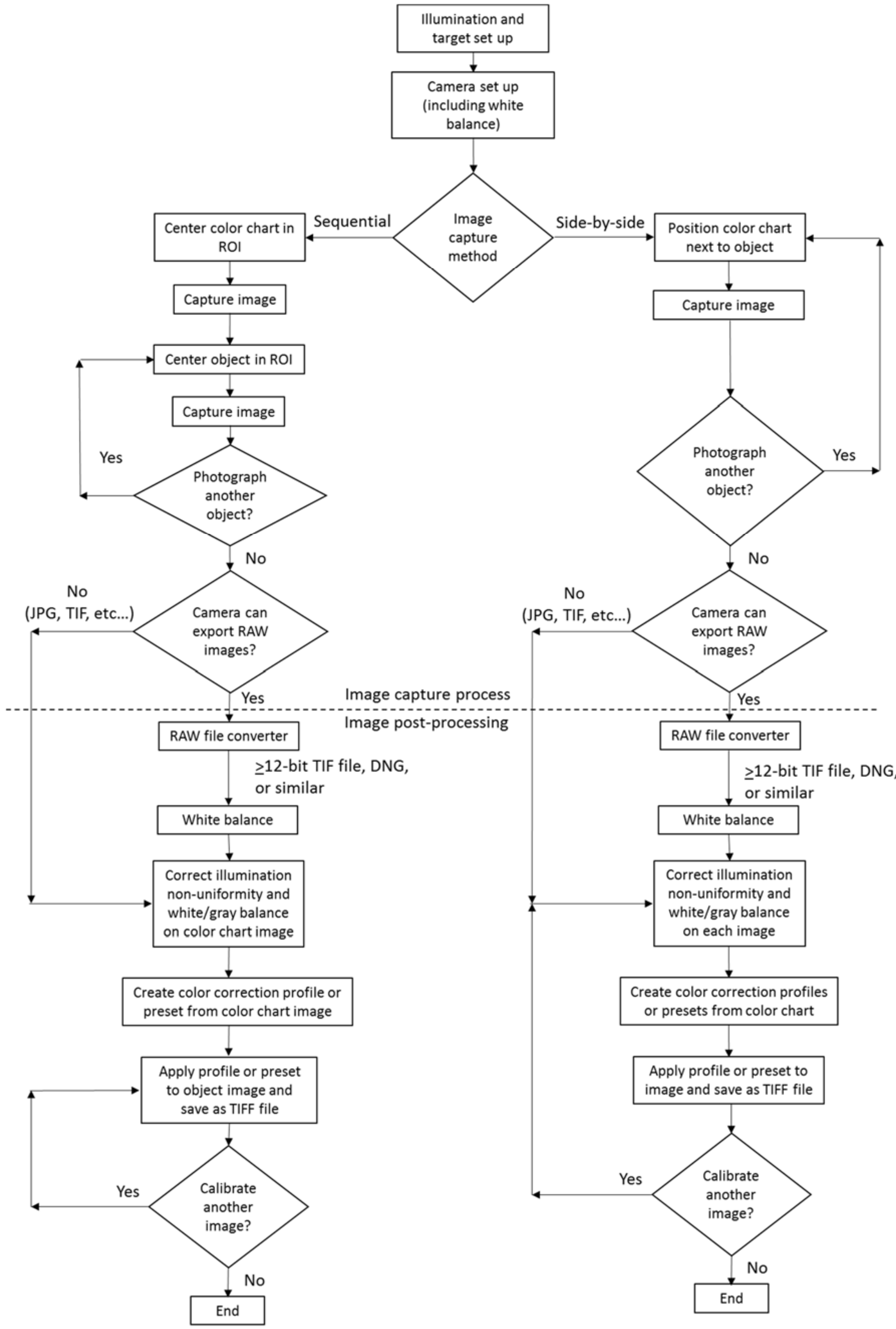
Appendix A

Flowchart of Camera Image Capture and Color Correction Workflow



Appendix B
Recommended Color Image Capture and Color Correction Procedure

This general procedure outlines a recommended digital camera image capture workflow that can be used to improve image color accuracy and consistency. The process is outlined in the flowchart given in Appendix 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 (e.g., HIPAA). However, most healthcare organizations include a statement in the consent that patients sign when they agree to the medical services being provided, that says they are aware that photographs may be acquired and used as part of their routine medical care and will be included in their record. There is much debate recently, however, as to whether photographs acquired by patients and transmitted to their physicians should become a part of the medical record.

Required equipment:

- Digital color camera with white balancing capability and a minimum resolution of 3 megapixels (MP).
- 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 colorimetric 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 the image file with a tag corresponding to the appropriate standard color space (e.g. sRGB).

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. Set up the illumination and background for photographing the object of interest. The background should be a uniform matte color, ideally a gray with 18% reflectance. The camera field of view, should 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 Fig. 4.
3. The object (e.g., body part) 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. The choice of method to some extent depends on the part of the body being imaged and the comfort of the patient. Place a uniform diffuse (ideally 18% 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 Fig. B.1 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 the given 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 B.1: 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 Fig. B.2). 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 skin tones).
8. Set the camera exposure so 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 Appendix 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 images with a tag corresponding to a standard color space (e.g., sRGB).
10. For the side-by-side method, place the color chart adjacent to the object of interest (see Fig. B.2) 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 images with a tag corresponding to a standard color space (e.g., sRGB).

Figure B.2: 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 image editing program to ensure that the gray levels are scaled correctly. The gray level 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. The darkest patch is then 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 gray level 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 gray level-scaled reference color chart image, and create a Hue, Saturation, Luminance (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 gray level scaling and color correction for each side-by-side image. An example of a color-corrected image is shown in Fig. B.3.

Figure B.3: 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).

Appendix C
Further color management considerations

ICC color management is universally used to handle transforms between devices and color spaces, as it provides a robust, well-proven and flexible architecture that is widely implemented. One key reason for the success of the ICC profile is the use of a well-defined Profile Connection Space (PCS), which is in effect a virtual color space that all ICC profiles connect to [10Since different media have different dynamic ranges, they cannot be matched exactly and so the default procedure in ICC color management is to scale all data to be media-relative. When transformed via the PCS, this has the effect of matching one media white point to another, regardless of its luminance or chromaticity. The case where an exact colorimetric match is required is supported for reflective media relative to a perfect reflecting diffuser through the ICC-Absolute Colorimetric rendering intent. It cannot be supported for displays as there is no independent adapting white point for display viewing other than the display white itself [16].

Image state and rendering

In the majority of cases, images captured by camera will be transformed (or ‘rendered’) so that they appear pleasing when viewed on a display. This may be done by in-camera firmware when saving images in JPEG format, or subsequently in a RAW convertor when processing camera RAW images. Images which have undergone this rendering process for display viewing (or printing) are said to be ‘output-referred’, while images which are encoded so that the original scene colorimetry is preserved are said to be ‘scene-referred’ [5]. The methods used to render to output-referred image state (such as in-camera processing to produce JPEG images) are generally proprietary and undocumented, which makes it difficult to obtain accurate colorimetry from an output-referred image. If the rendering method is known, it may be possible to invert the transform to recover the original colorimetry

Supported transforms

The ICC architecture incorporates processing elements that perform the conversion between data color encoding (such as RGB camera data) and the PCS. These elements include single-channel curves (which can be defined as a gamma value, look-up table or function), matrices and multi-dimensional color look-up tables (CLUTs). In ICC v2 and v4, profiles can be constructed from just a curve per channel and a matrix, or as a series of curves, matrix and CLUT [10].

Scene-referred colorimetry with ICC profiles

When the goal is to capture scene colorimetry, two approaches are possible using ICC color management [17].

1. Custom profile for camera/illumination
2. Standard scene-referred profile

A custom camera profile converts from camera RGB to the ICC PCS. It has to be built for the particular camera (including its exposure settings, lenses etc) and scene illumination. Examples and further information can be found on the ICC web site in the Digital Photography section and the Profiles section [18, 19]. The working space should be set to ProPhotoRGB to prevent clipping, and image data should be 16-bit precision. The media white point can have a maximum of 200 cd/m2, twice that of the PCS, which should be adequate for most uses although may lead to inaccuracies when very high luminances are captured.

For many applications where scene-referred colorimetry is the goal, it is preferable to convert images to a standard scene-referred profile. If the image data is 16-bit, the linear_RIMM-RGB_v4.icc profile is recommended for this purpose. This profile, and the suggested procedure for converting to it, are documented on the ICC site [20].

The use of the different rendering intents in ICC profiles for different reproduction goals is described in references [17] and [20].

Standard output-referred encoding with ICC profiles

Images in medical photography are created primarily for viewing by medical practitioners on displays. Scene-referred image data is not suited to viewing directly on a display, due to differences in dynamic range and color gamut. Images are converted to an output-referred state by non-linear compression of dynamic range and gamut adjustment. In many cases the conversion also incorporates adjustments that creates more pleasing images.

An output-referred encoding is one which can be realized on a given reproduction system, and several standard encodings of this type exist. The ICC 3-component encoding registry provides full details of the available standard encodings [23]. The most widely used are sRGB [24] for CRT-like color gamuts, and Adobe RGB (1998) [25] for extended gamuts.

To convert to the chosen standard out-referred encoding, the recommended procedure is to perform a conversion from scene-referred (with the linear_RIMM-RGB_v4.icc profile as source) to the profile for the output encoding, using the Media-relative Colorimetric rendering intent. Profiles for sRGB and Adobe RGB (1998) encodings are widely available, but ICC provides recommended v2 and v4 profiles for sRGB [?].

Workflow

If a custom profile is generated for a camera capture condition as described above, it can be assigned to an image so that when the image is converted to another color space the profile is used to convert the image data to the PCS before the data is then converted to the color space of the destination profile. After the profile is assigned, an image can be saved with the profile embedded. Most image file formats support embedded ICC profiles, and a full list of such formats is available [21].

Professional image applications support and correctly interpret ICC profiles. However, it should be noted that some applications that provide image previews are not color management-aware, and will therefore render the image RGB data directly to the screen without interpreting the embedded profile. Some automated workflow applications also strip any embedded profiles on parsing the image.

As discussed above, it is recommended that the color management working space is set to ProPhoto RGB or other large-gamut encoding to avoid gamut clipping. Images are not saved in ProPhoto but converted to either scene-referred or standard output-referred encodings.

The ICC PCS (in ICC v2 and v4) is based on D50 colorimetry, and where the measured data used to characterize a camera, display or printer is not D50 a chromatic adaptation transform must be applied so that all data stored in the profile is D50. When interpreting the colorimetry of an image, it is therefore necessary to invert the chromatic adaptation transform and undo the media-relative scaling in order to determine the original colorimetry of the image.

iccMAX

The recommendations in this section apply primarily to v4 ICC profiles, currently the most widely used version. V2 profiles can also be used for camera profiles, although results may be less predictable. Either v2 or v4 profiles can be used as destination profiles.

ICC has released a new specification, iccMAX, which extends the functionality of the ICC architecture. iccMAX profiles can be used with v4 profiles where the PCS is colorimetric, but iccMAX also supports use of spectral, material and alternate colorimetric PCS, for example where the capture device is multi-spectral, where the input channel represent amounts of different materials rather than solely color, or where it is desired to use a colorimetry other than D50 in the PCS. More information on iccMAX is available [22].

Appendix D

Basic considerations for better color consistency

The best results for color consistency will be achieved by following the detailed recommendations given in Appendix A and B. However, if it is not possible to completely for this guidance, then the following minimal considerations should be followed:

Subject illumination:

1. Use stable and uniform diffuse illumination. Avoid shadows and highlights.
2. Use a broadband white light source that approximates the daylight spectrum.
3. The background should be a neutral gray color.
4. The surface of interest should be roughly perpendicular to the camera's optical axis.
5. Maintain the same lighting conditions for all images.

Camera setup:

1. Set camera to the proper white balance and exposure time. Avoid over or under-exposure. It is better to be a little under-exposed than a little over-exposed.
2. Use a RAW file format with the least image enhancement. If not possible, use uncompressed $\geq$12 bit TIFF files.
3. Properly frame and focus the object surface.
4. Avoid flash photography.
5. Turn off and spatially-dependent processing, such as high dynamic range or relighting.
6. Save images in the sRGB color space with a D65 white point.
7. Maintain the same camera settings (except for exposure time if lighting intensity varies).

Rendering the image:

1. Use image viewing software that properly recognizes the file format.
2. Use an sRGB display.

Imaging and reproduction of Skin

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Objectives:

- Understand the challenges in measurement and reproduction of skin
- Clarify the requirements of different users of skin reflectance data
- Review best practices in skin measurement and reproduction
- Agree a method of estimating skin reflectance from RGB image data
- Develop a publicly accessible database of skin images and skin reflectance data

Why Spectral Reflectance?

- **Physical property**

  Independent of illumination

- **More informative**

  True colour simulation and reproduction

  Direct connects with skin chromophores

  - melanin, haemoglobin

Important measure to medicine

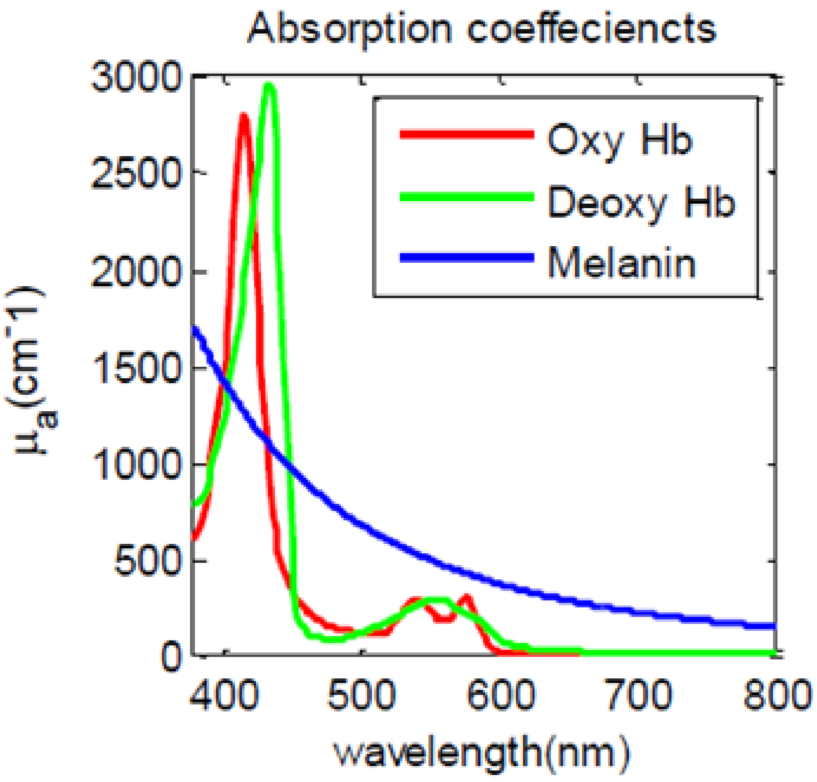
Melanin:

-protects from UV radiation

-responsible for ethnic skin colour differences

Haemoglobin – two dimensions

- Concentration in blood
- Oxygenation saturation



Skin image spectra estimation

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To estimate skin spectral reflectance from camera digital signals

Step 1: Camera profiling

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

Step 2: Spectral reflectance re-construction

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

Skin image spectra estimation

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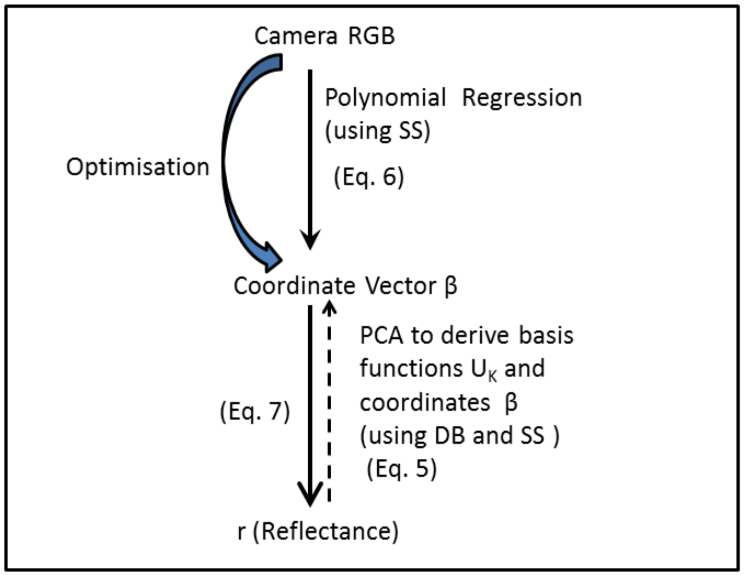

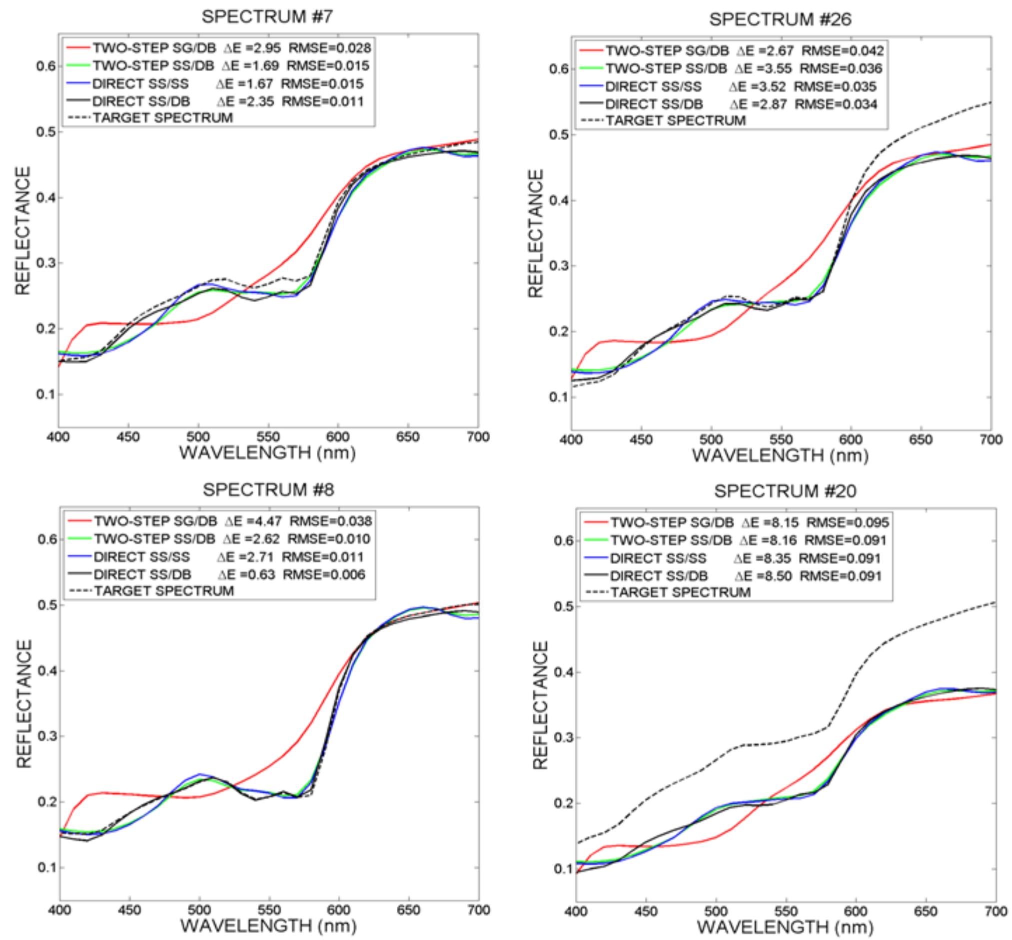

Kaida Xiao, Yuteng Zhu, Changjun Li, David Connah, Julian Yates and Sophie Wuerger (2016), Improved method for skin reflectance reconstruction from camera images, Optics Express, 24, 13, 14934-14950.

Skin spectra database

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