The advantages of spectral color characterization

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Color Image Workflow

A/D Converter

Camera RAW (device dependent)

Camera compensation:

- Exposure Adjustments
- White balancing
- Sensor characterization

Scene editing (re-lighting, etc.)

Scene-referred color encoding (device independent)

Color Rendering:

- Tone mapping
- Gamut mapping
- Color preference

Output-referred color encoding (device independent)

Display color transform

Softcopy image (device dependent)

Printer color transform

Hardcopy image (device dependent)

Picture editing (add text, etc.)

from ISO 17321-1

Color correction matrix

The most simple form is a 3x3 matrix – the color correction matrix

$$\begin{bmatrix} R_{camera} \\ G_{camera} \\ B_{camera} \end{bmatrix} \begin{bmatrix} a_1 & a_2 & a_3 \\ b_1 & b_2 & b_3 \\ c_1 & c_2 & c_3 \end{bmatrix} = \begin{bmatrix} X \\ Y \\ Z \end{bmatrix}$$

Sensor-output

Color correction matrix

CIE XYZ

device dependent

device independent

Color correction matrix

More advanced system use Multidimensional Look-up-Tables (MLUT)

$$\begin{bmatrix} R_{camera} \\ G_{camera} \\ B_{camera} \end{bmatrix} MLUT = \begin{bmatrix} X \\ Y \\ Z \end{bmatrix}$$

Sensor-output

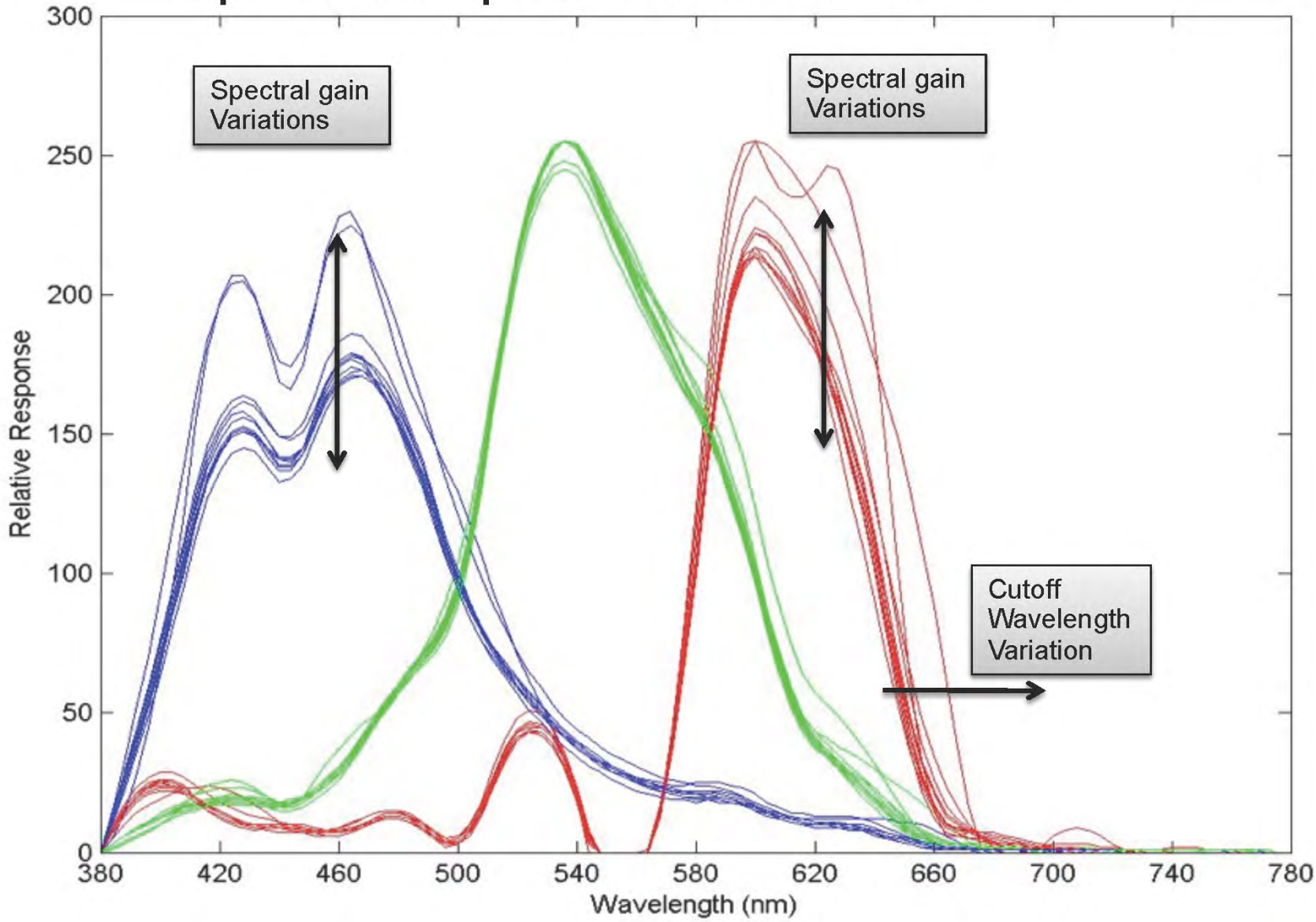
Multidimensional Look-up-table

CIE XYZ

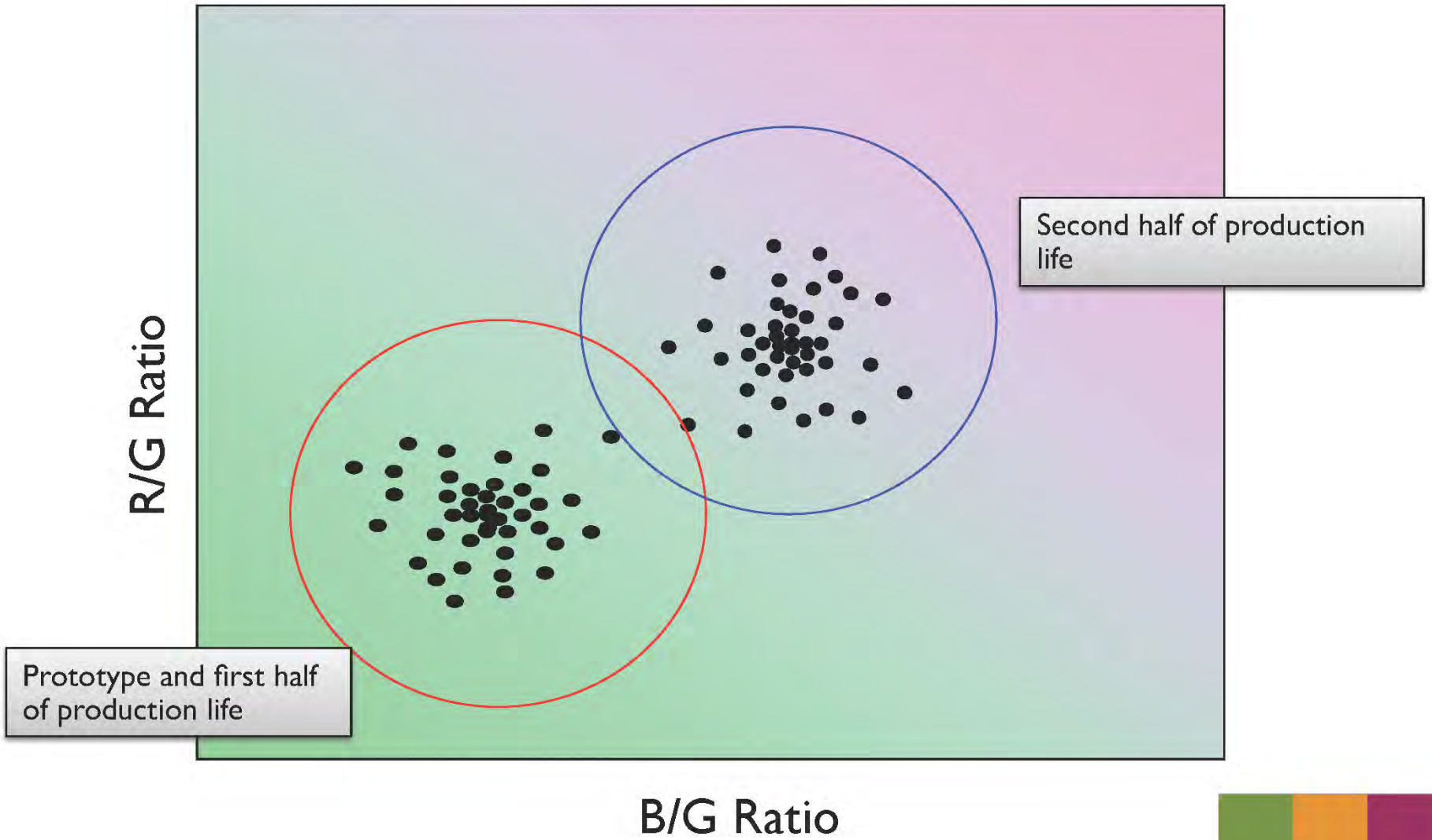
device dependent

device independent

Spectral response of 11 modules



Chromaticity ratio variation seen mid-way through production.



imageQuality basics

Color variation between individual and class calibration.

Individual Calibration

Average calibration (class calibration)

Characterization methods

In general, there are two different methods to obtain the Camera Characterization matrix

- Chart-based method
- Spectra-based method

Chart-Based Method

RGB values created by the camera.

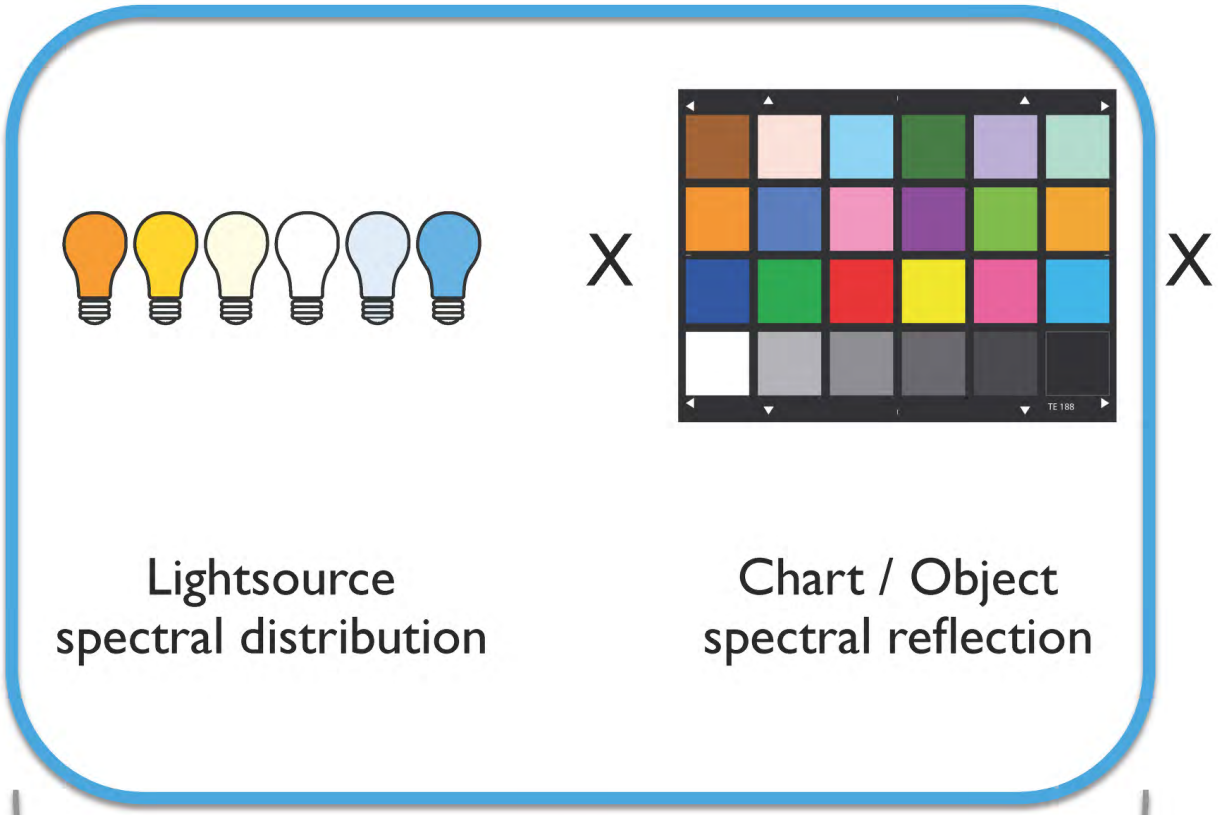
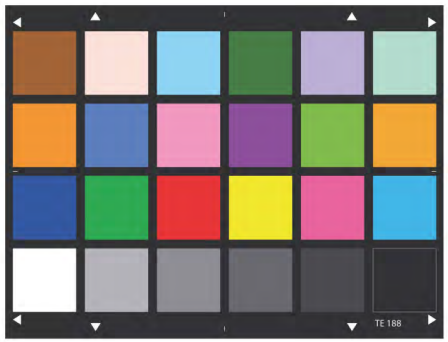
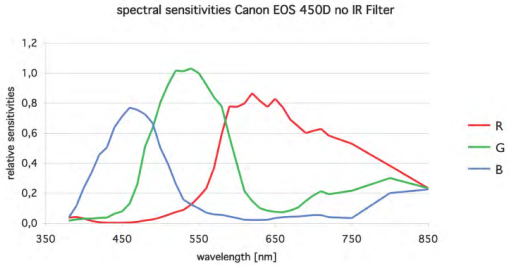


Chart-Based Method

X



X



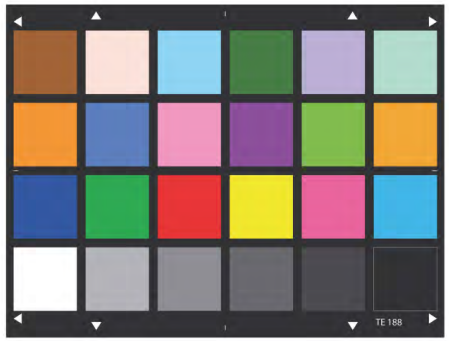
= RGB

Lightsource
spectral distribution

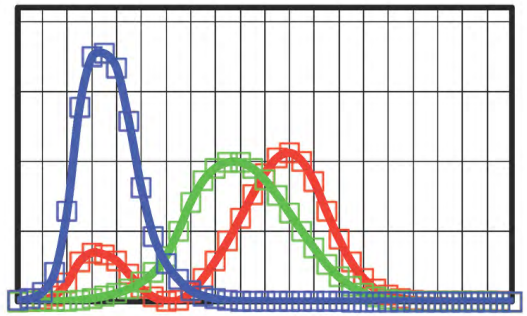
Chart / Object
spectral reflection

Camera / human
spectral sensitivity

X



X



= XYZ

Chart-Based Method

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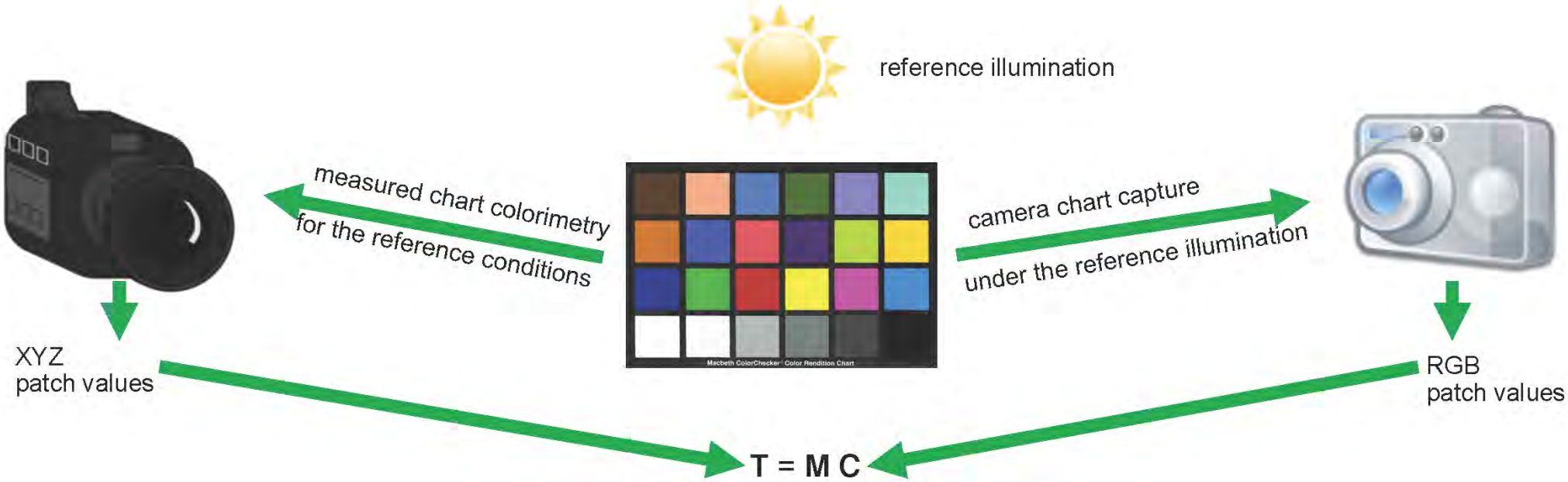
C M T

device dependent

device independent

Chart-Based Method



Idealized, assuming raw, linear, and noiseless where **M** is the estimator to be determined that transforms between camera responses **C** and tristimulus values **T** that minimizes colorimetric residual errors:

$$|| \mathbf{MC} - \mathbf{T} ||^2 \Rightarrow 0$$

First by linear estimation:

$$\mathbf{M} = \mathbf{T}\mathbf{C}^t(\mathbf{C}\mathbf{C}^t)^{-1}$$

Generally followed by nonlinear optimization in perceptual coordinates (e.g. L*a*b*, CIECAM02):

$$\text{Iterate } \mathbf{M}: || \Delta E ||^2 \Rightarrow 0$$

$f(\mathbf{T})$ vs. $f(\mathbf{MC})$

*Degrees of freedom can be reduced by constraining **M** to the scene adopted white point*

Spectra-based method

$$R_{Camera} = k \cdot \int_{380nm}^{780nm} s(\lambda) \cdot r(\lambda) \cdot c_R(\lambda) \cdot d\lambda$$

$$G_{Camera} = k \cdot \int_{380nm}^{780nm} s(\lambda) \cdot r(\lambda) \cdot c_G(\lambda) \cdot d\lambda$$

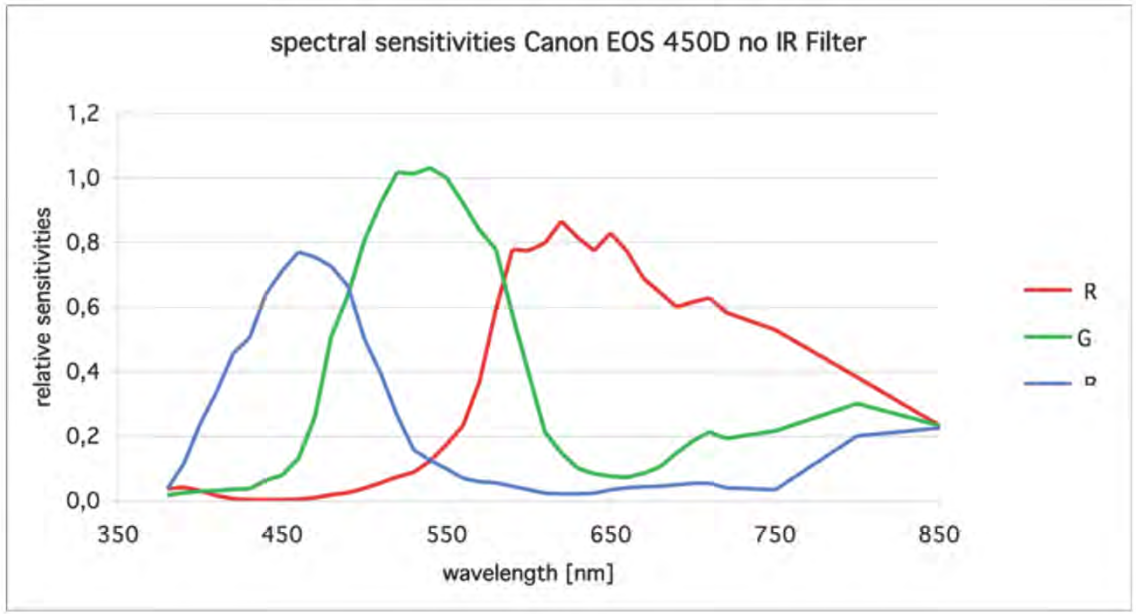
$$B_{Camera} = k \cdot \int_{380nm}^{780nm} s(\lambda) \cdot r(\lambda) \cdot c_B(\lambda) \cdot d\lambda$$

with:

s(λ) spectral distribution of the light source

r(λ) spectral reflectance of the object

$c_X(\lambda)$ spectral sensitivity of the camera



Spectra-Based Method

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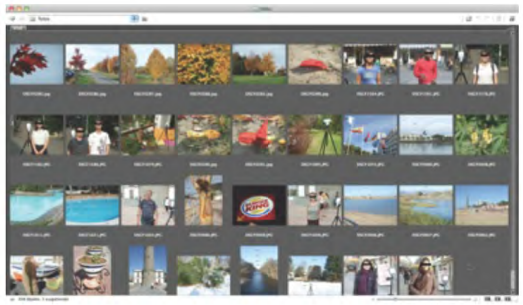

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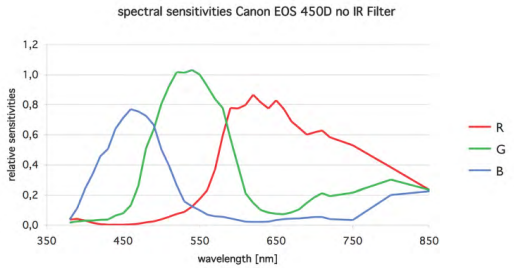


= RGB

Lightsource
spectral distribution

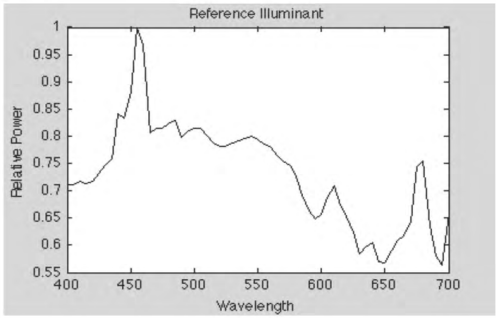
Chart / Object
spectral reflection

Camera
spectral sensitivity

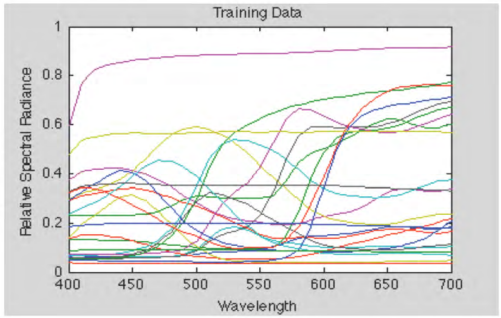
Intended simulation data

measured

Spectra-Based Method



X



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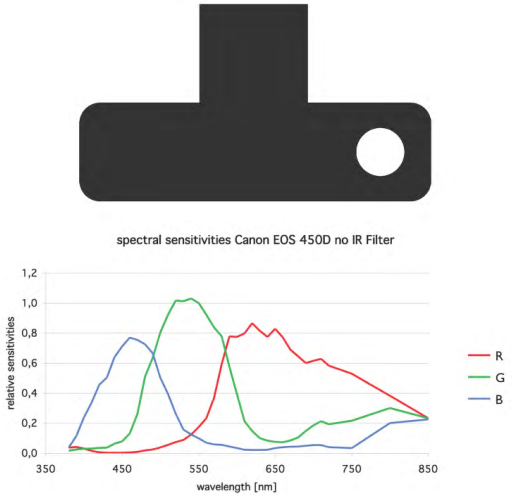

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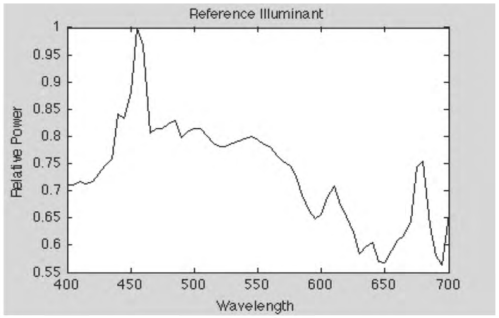

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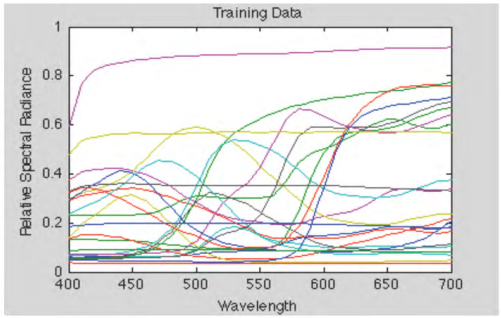

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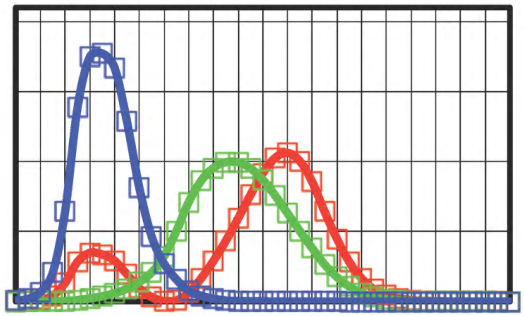
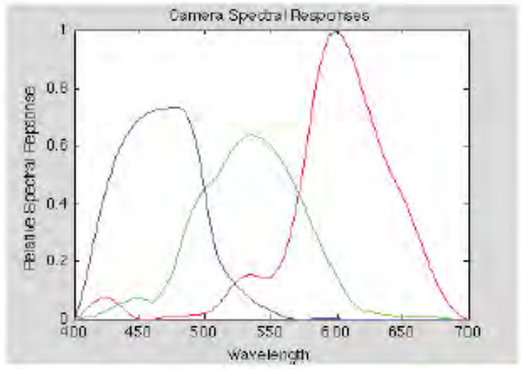


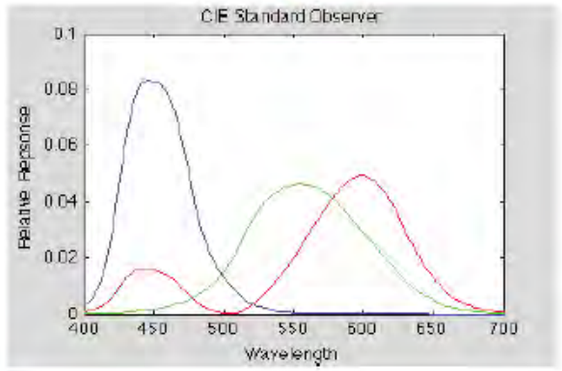
= XYZ

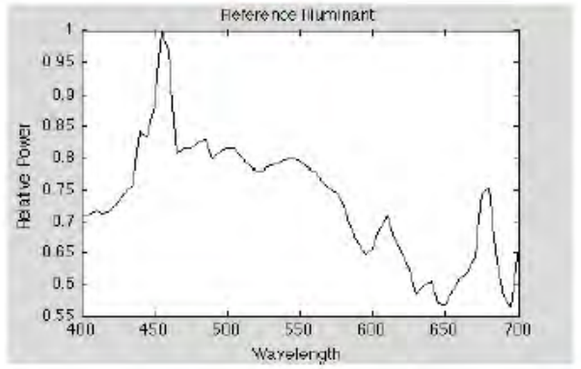
Spectra-based method

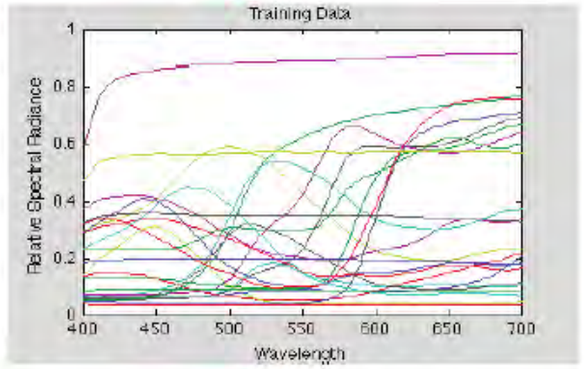
T = O I S

Training spectra colorimetric values









C = R I S

Training spectra camera values

then: **T** = **M C** as before

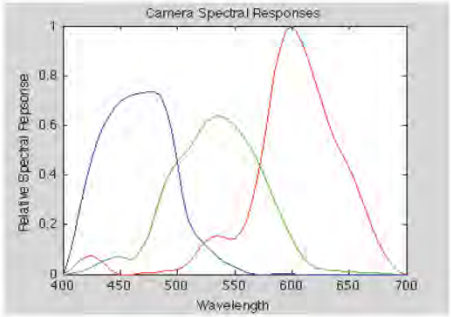
solve for **M** as illustrated previously

Tradeoffs

Chart:

- ✓ Simple, fast, and easy
- ✓ Minimal equipment required (target and colorimetric data)
- - Valid transform domain is limited to the target gamut and capture conditions
- - Multiple sets of target captures and pre-computed transforms required for each Original Scene adopted white point
- - Chart colorants are not generally representative of likely Original Scene objects resulting in metameric errors
- - Limited to low-dimensionality transforms (matrix)

Spectra:



- ✓ Transform can be computed for any Original Scene adopted white point
- ✓ Training data is selected to be representative of Original Scene objects and radiation modes thereby minimizing metameric errors and optimizing for the likely use-cases
- ✓ Transforms are robust over a wide range of capture conditions and radiation modes
- ✓ Transforms are easily updated
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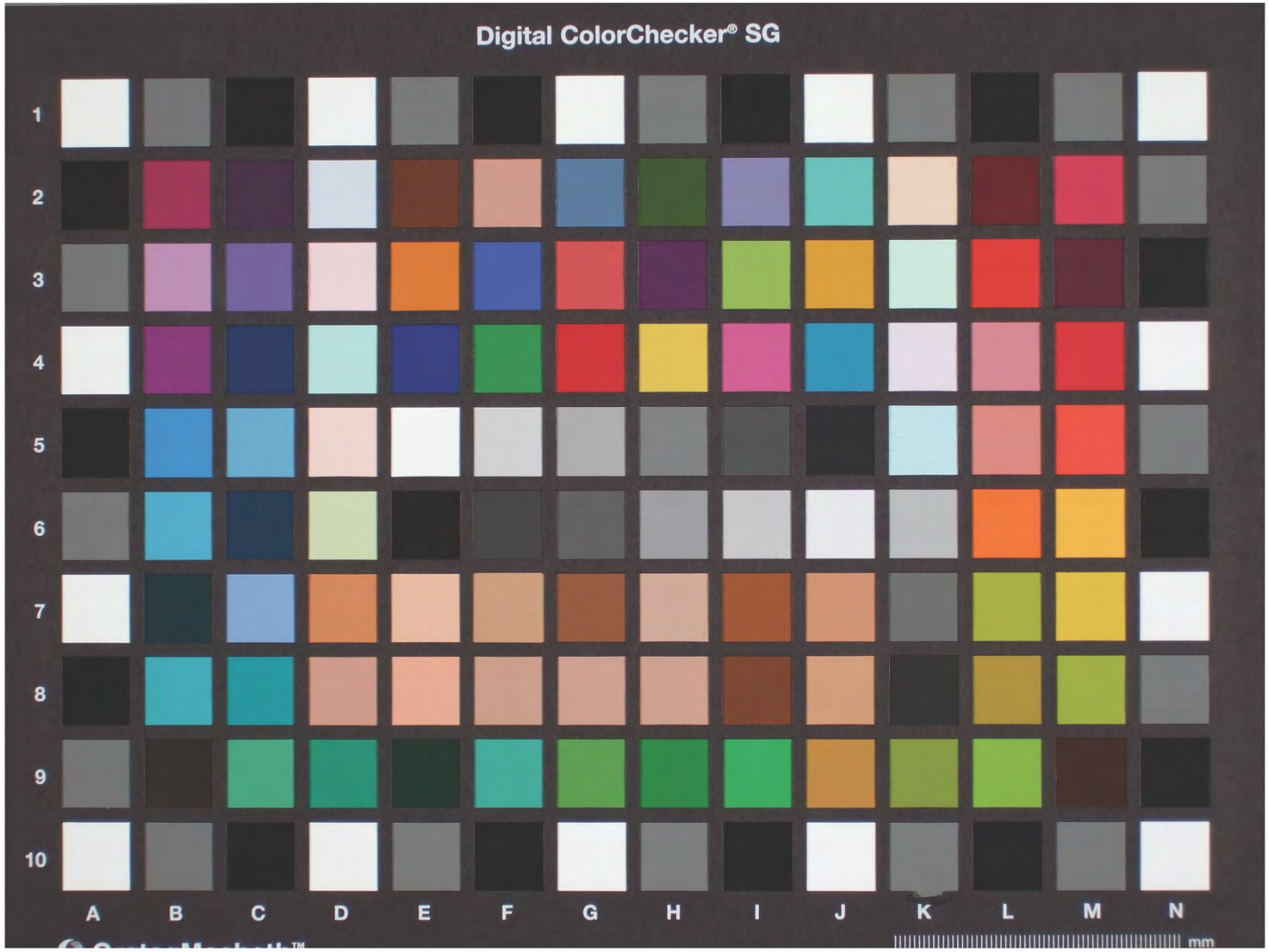
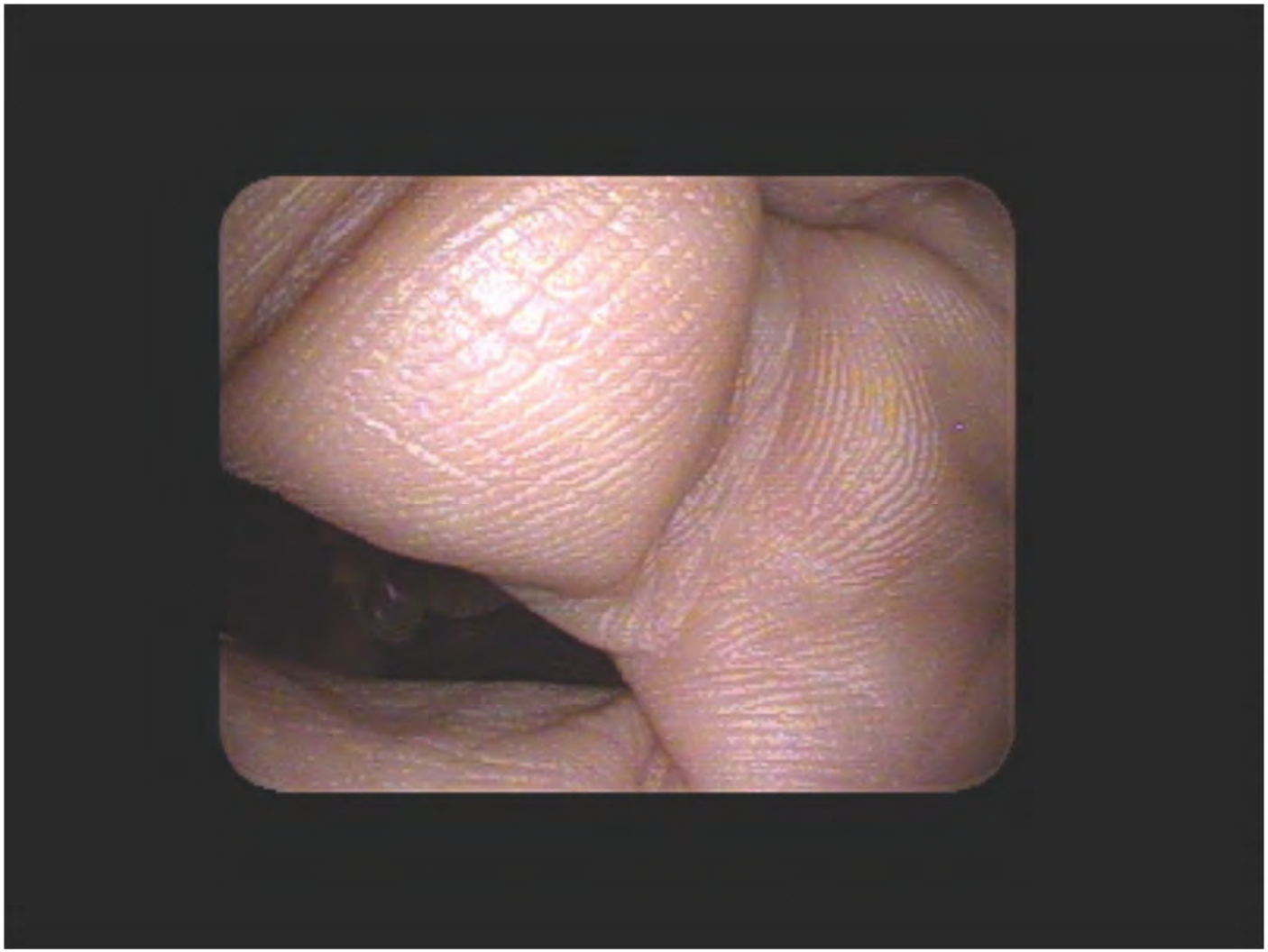
- - Requires to measure camera spectral sensitivities

X-Rite ColorChecker SG



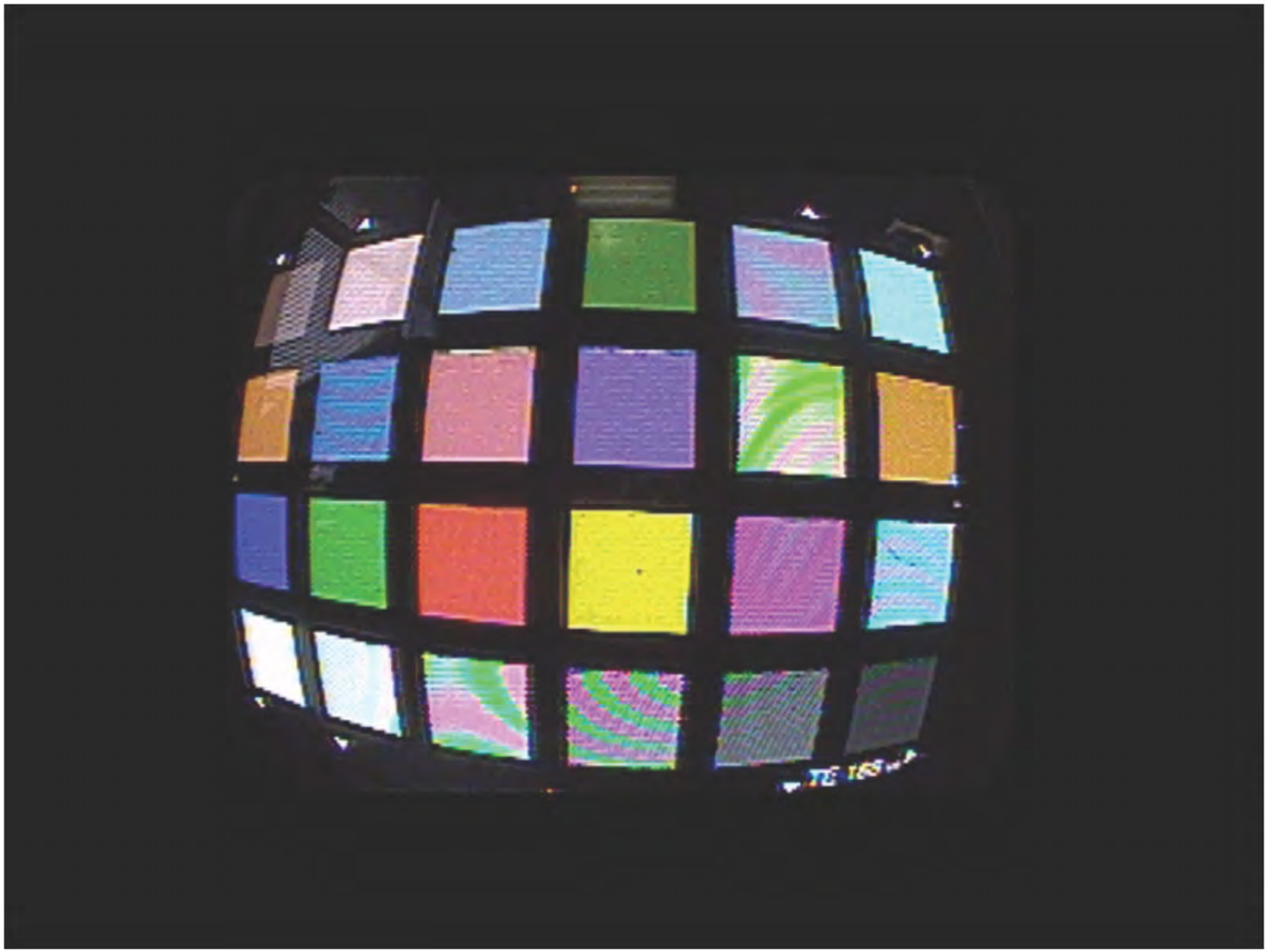
Color Chart used in Photography

Endoscopy



Medical Imaging has different challenges for ColorCharts

Endoscopy



Small charts are not easily produced

Tradeoffs

Chart:

Maybe not true for medical imaging

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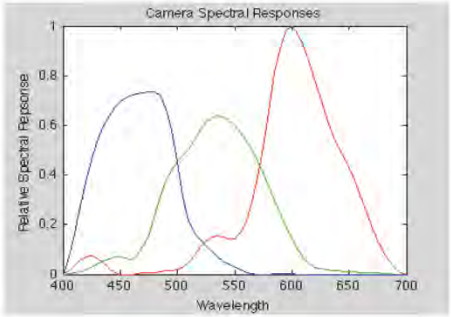
Spectra:



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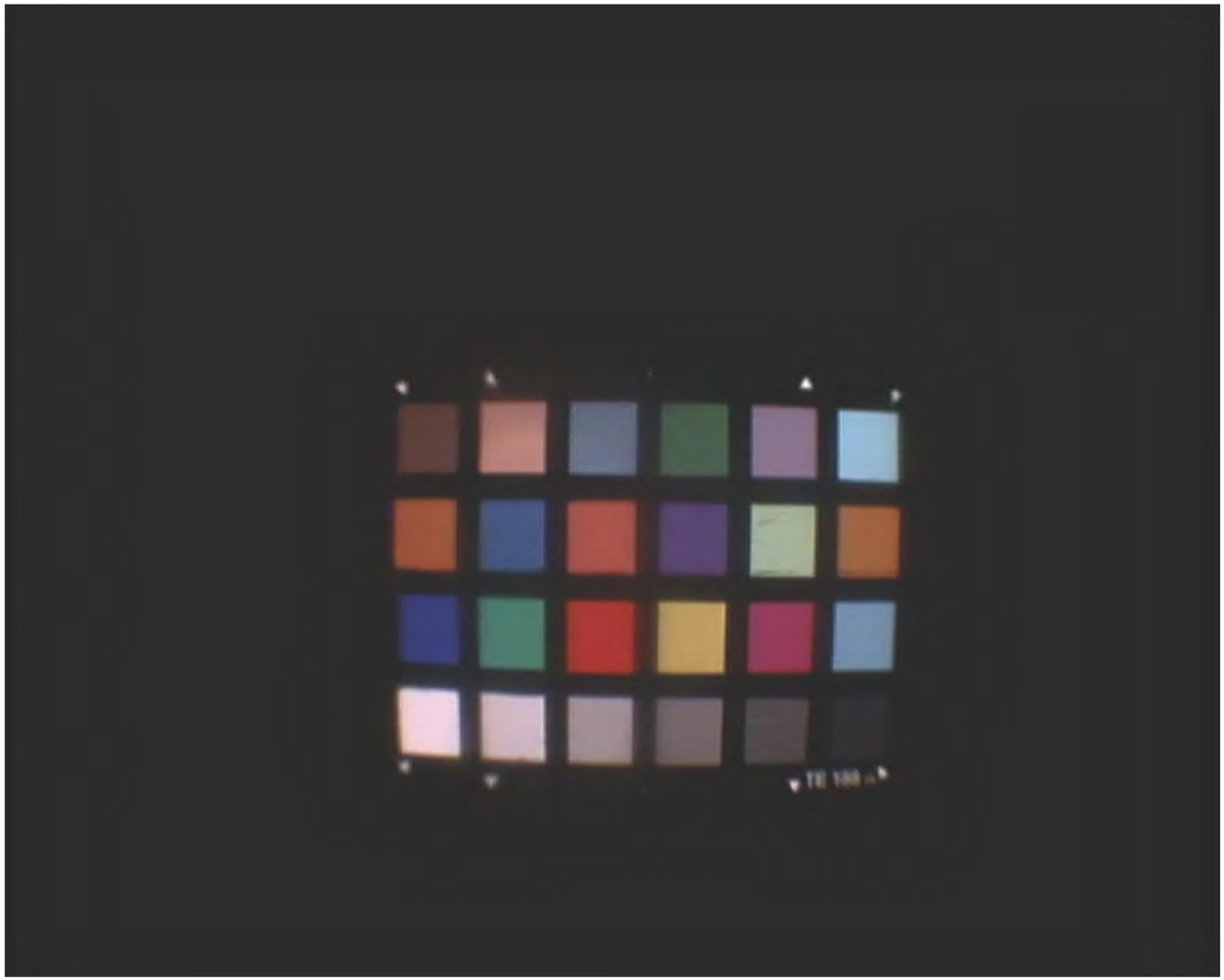
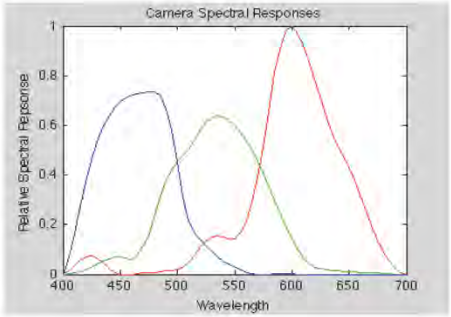


The maximum possible amount of patches is limited

Tradeoffs

Chart:

Spectra:



Strong limitations for medical imaging

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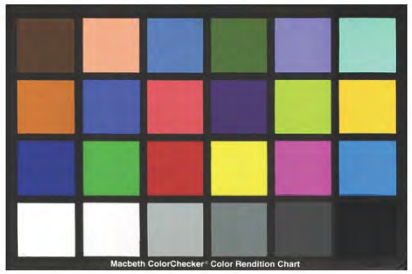
Database

Chart vs. „real live“ ™



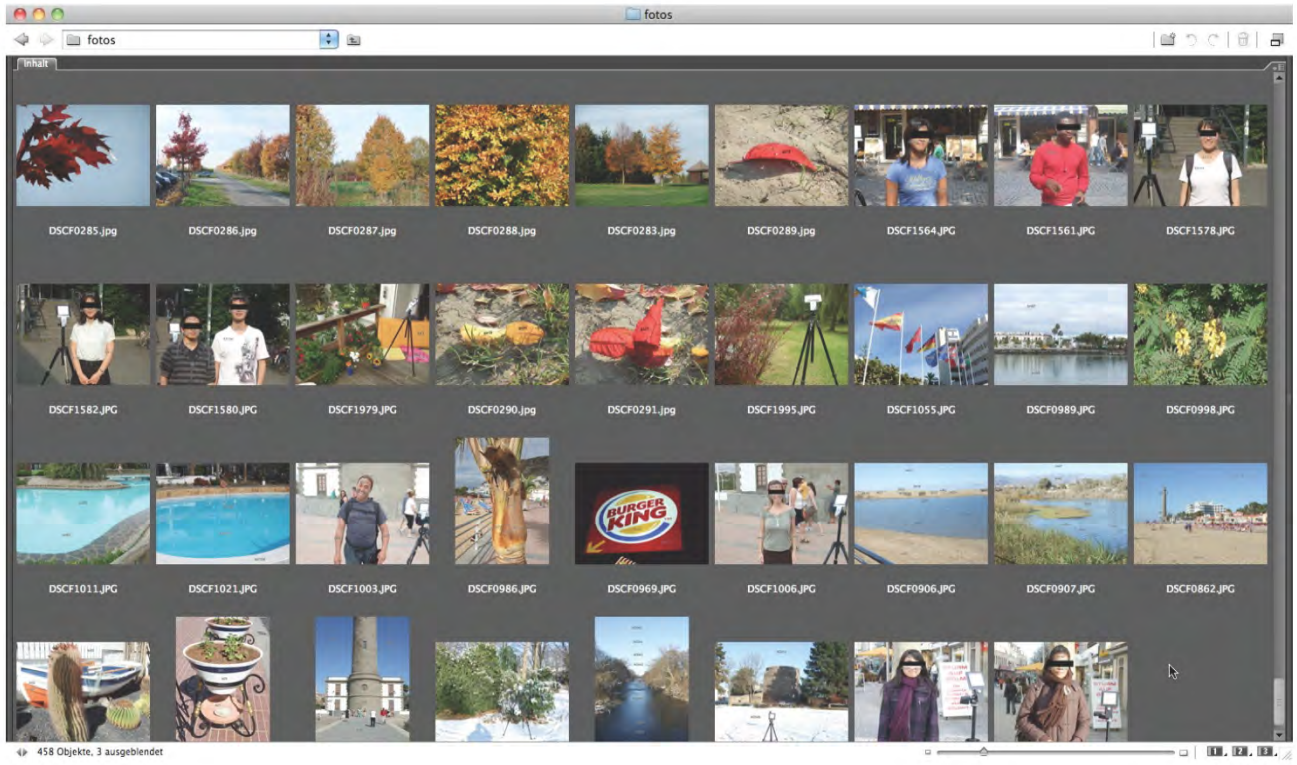


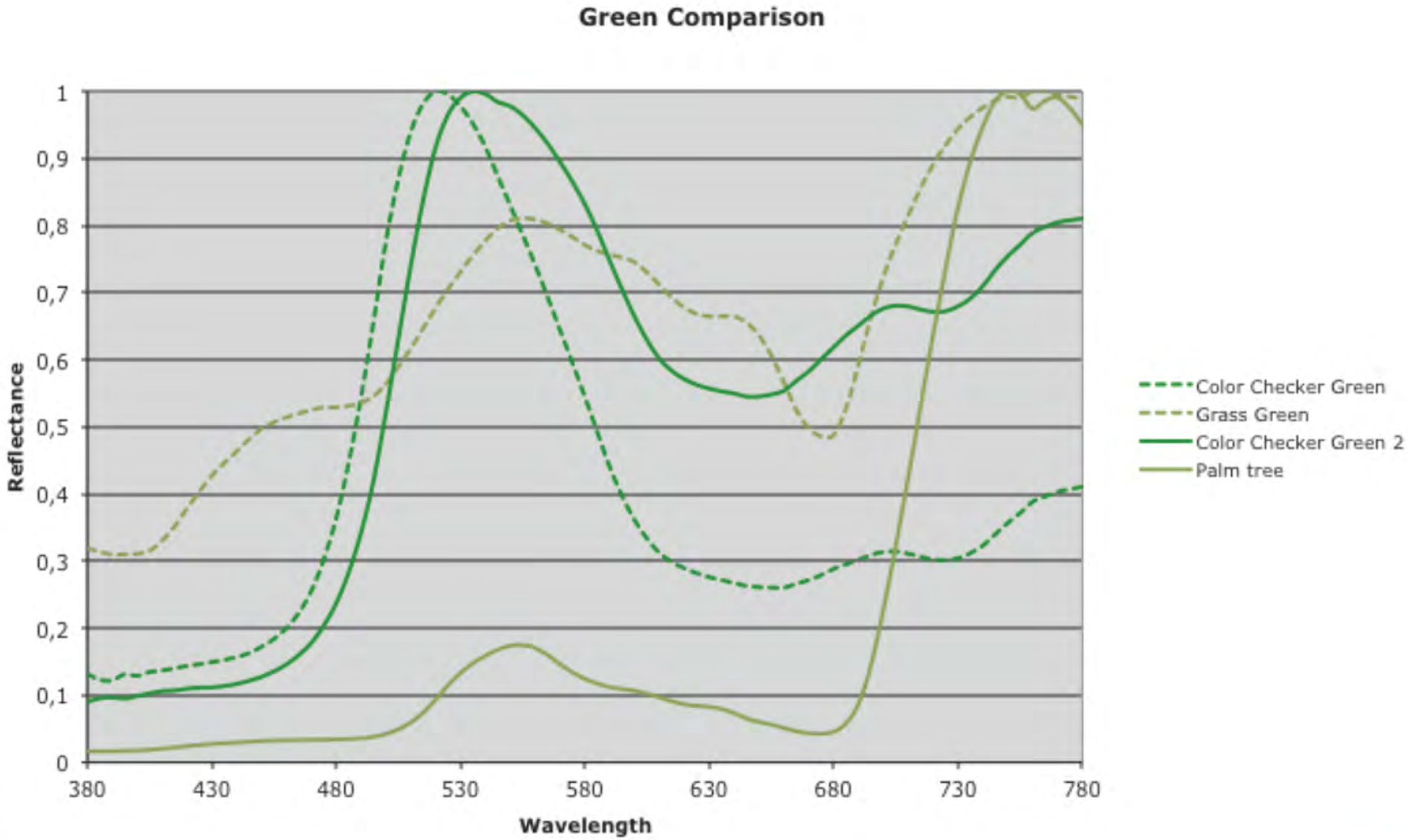
Figure 1: An example for a typical measurement setup to measure skin tones.

Figure 1: The image shows a typical measurement setup to measure skin tones.

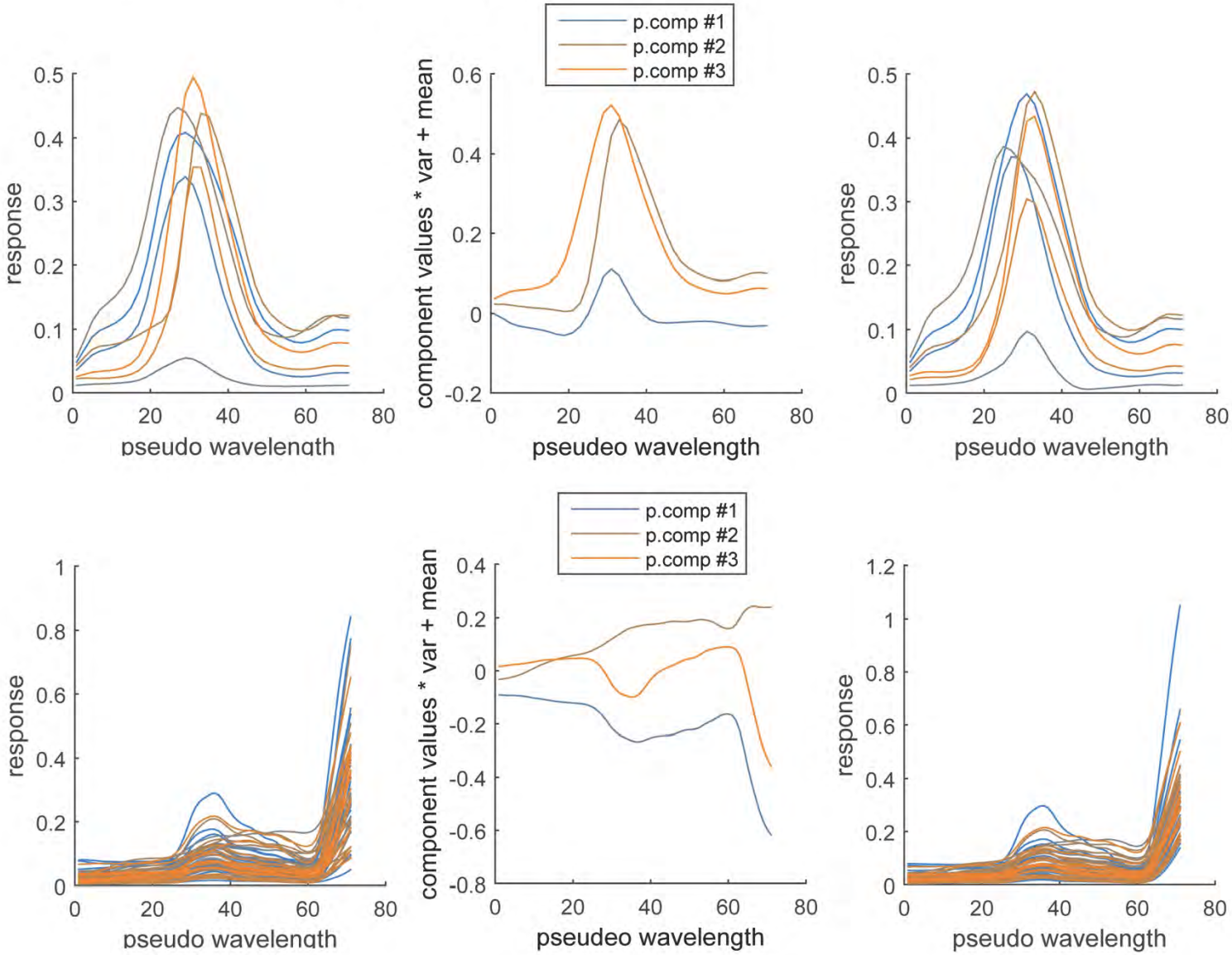
The setup


element details
add
back
original data:
response
wavelength[nm]
white tile corrected:
response
wavelength[nm]
ID
2440
storage ID
ea146
description
skin | arm
category
portrait
illumination
daylight sunny
color
skin asian
brightness level
highlight

Comparison of green tones



Principle component analysis of green colours



Upper row shows CCSG target patches, lower row in situ measured tones

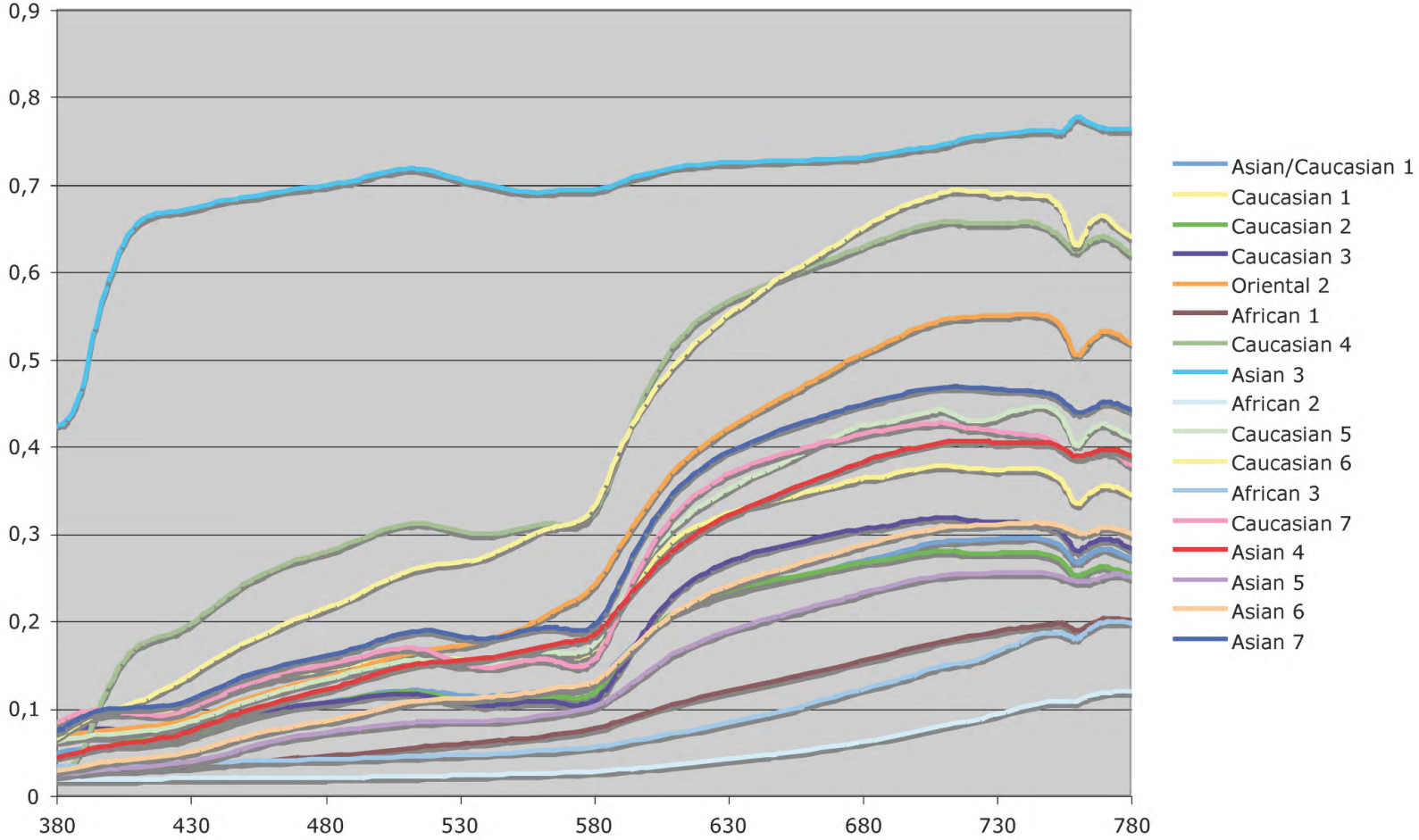


Figure 7: The comparison of a variety of skin-tones as white tile corrected spectral radiances.

INSITU DATA versus TAGET DATA

- Chart colorants are not generally representative of likely Original Scene
- This is especially true for medical applications as it is extremely hard to have e.g. “artificial skin”
- “in-situ” measured spectral radiances are a great help to optimize the color processing
- We are not aware that there is a database of “in-situ” measured spectral radiances of objects in the typical medical imaging use-cases
- Anyone interested in helping us to build one ?

Tradeoffs

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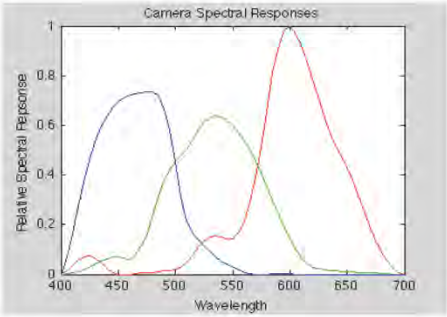

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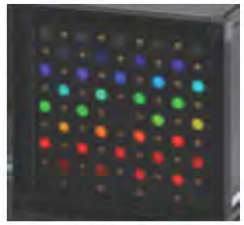
Spectral Sensitivity

	speed	cost	accuracy
Monochromator	slow	high	high
Filter based	Medium to fast	medium	good
LED based	fast	medium	good

Oriel MS257

camspecs

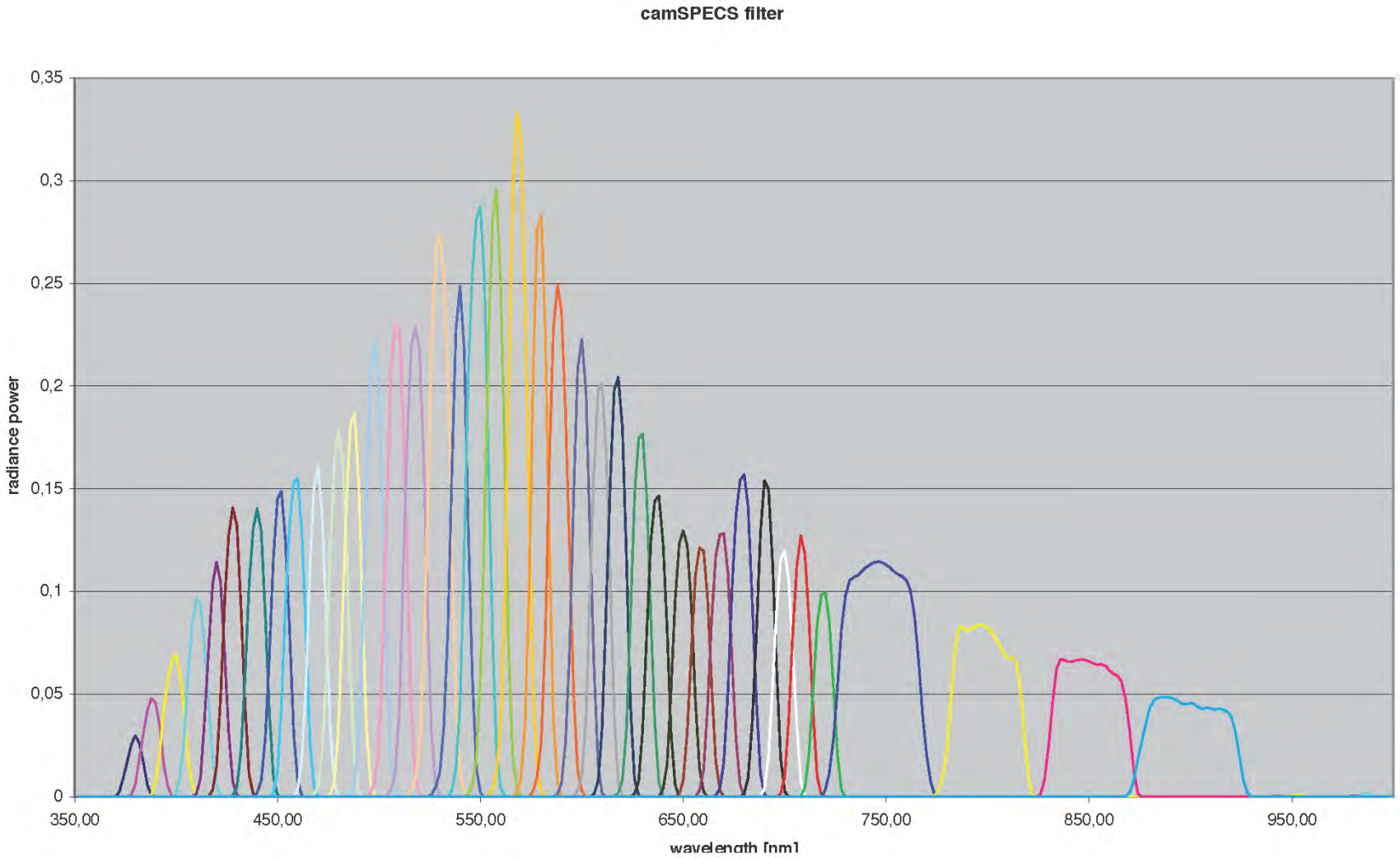


camspecs express

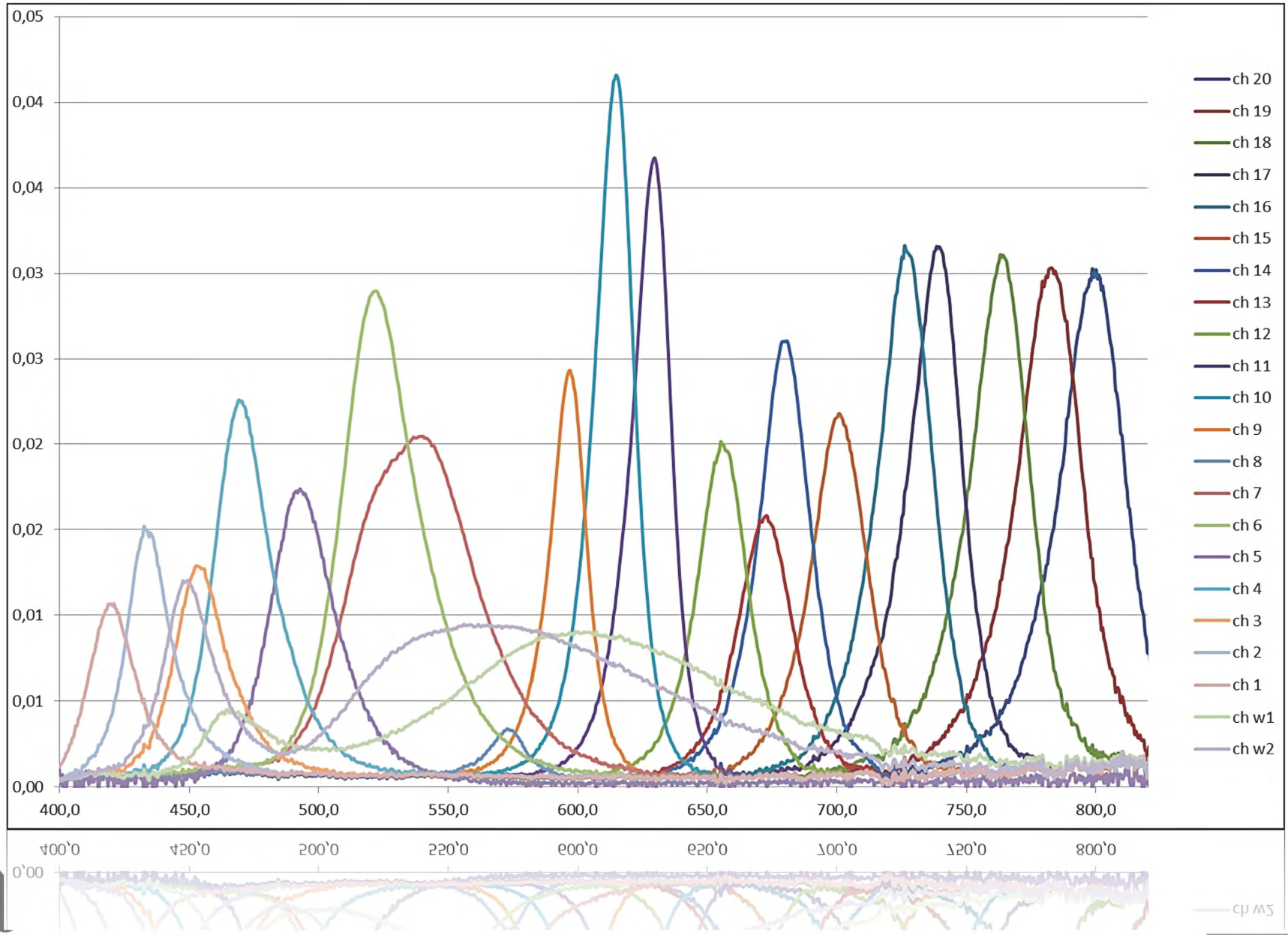
iQ-LED

Sample Hardware

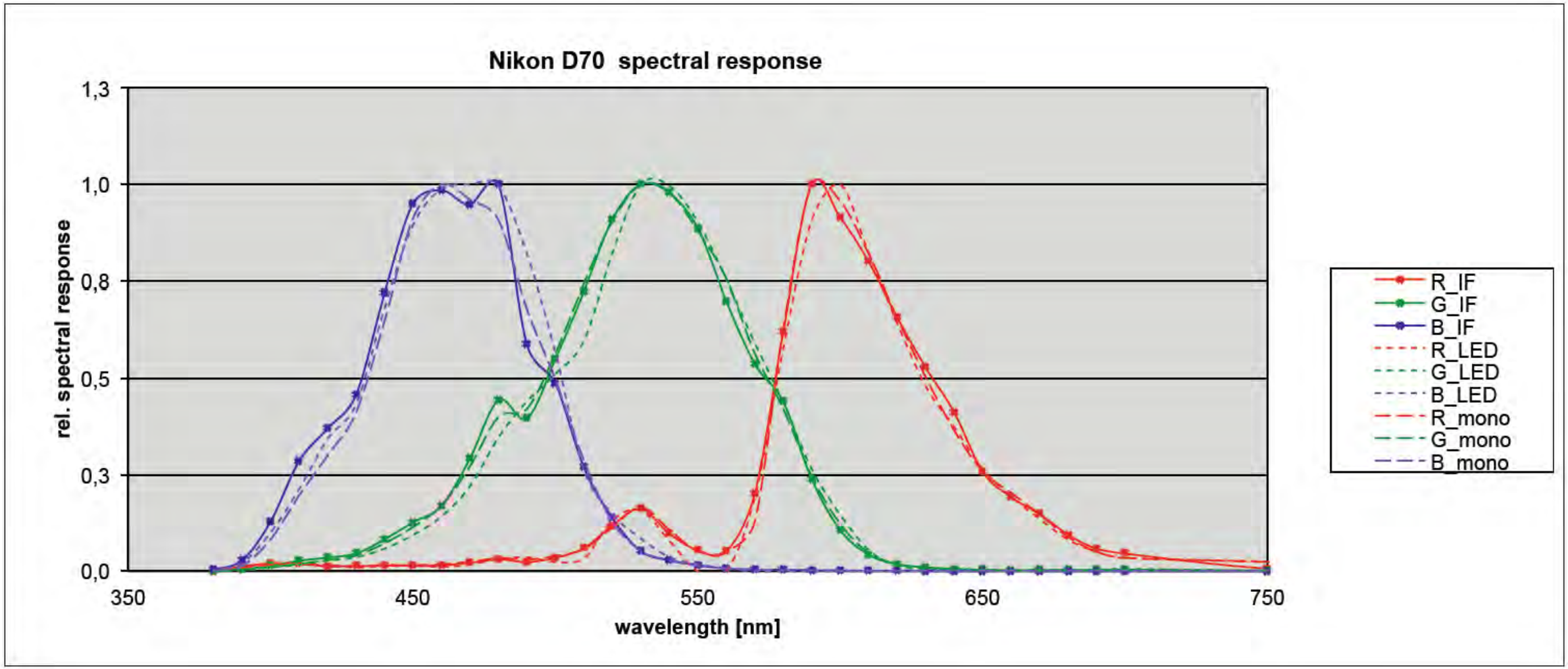
Interference Filter



Spectra of the 22 different LED Channels



- Measuring spectral sensitivities



Conclusion

- Individual Color-Calibration is important for best color reproduction
- The chart based calibration has various limitation, especially in the field of medical imaging
- The spectra based method is the better choice for use-case specific optimization
- Special “in-situ”-database for medical imaging would be very helpful

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