The Norwegian Colour and Visual Computing Laboratory

NTNU

Getting spectral data when you don't have spectral measurements

Tanzima Habib and Phil Green

The Norwegian color and Visual Computing Laboratory

Faculty of Computer Science and Media Technology

Norwegian University of Science and Technology

Gjøvik, Norway

syedath@studntnu.no

http://www.colorlab.no

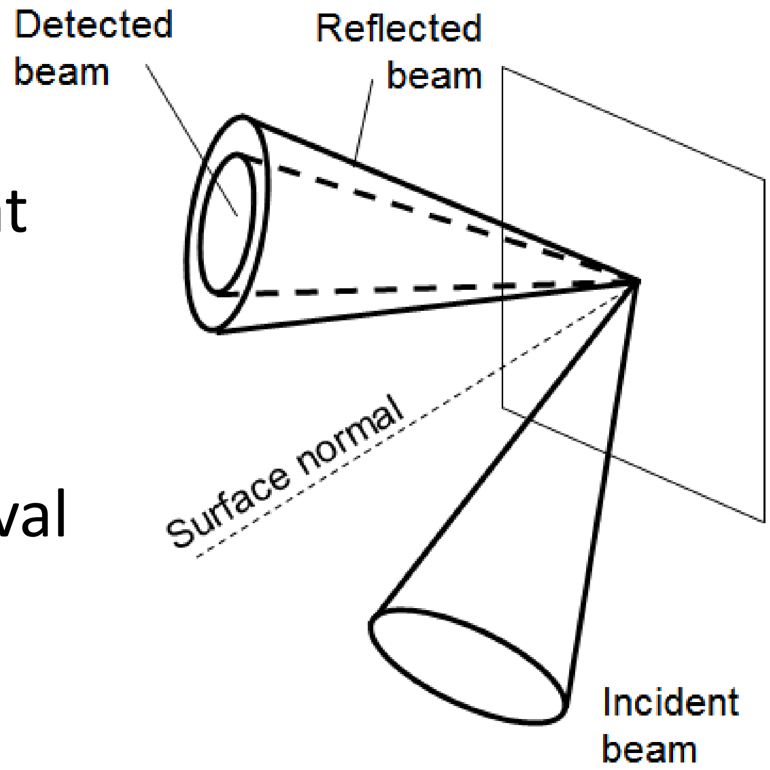
Aim

- There are many cases where the desired colour reproduction is defined spectrally – e.g. for brand colours
- Moreover, in a color management workflow it is now possible to use spectral data as input or to get spectral data as output using iccMAX.
- In many situations spectral data is not available. Therefore it is helpful to find ways to estimate spectral data from colorimetric values such as XYZ
- Our goal is to provide good estimates of spectral reflectance from tristimulus values

Reflectance factor

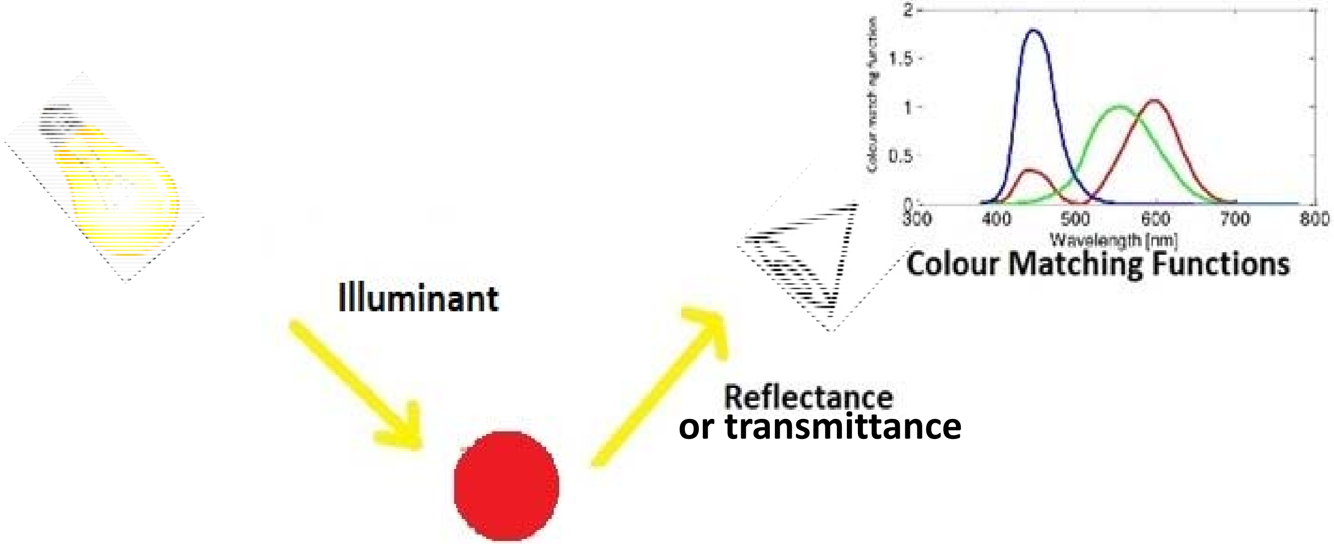
- "Ratio of the radiation reflected by a body delimited by a given cone to that reflected by the perfect reflecting diffuser identically irradiated or illuminated." (ISO 13655)
- This reflectance factor defined at specific wavelength intervals over the visible range.

E.g. 380 to 780 nm at 1 nm interval



Spectral data to tristimulus values

- We obtain XYZ and CIELAB from spectral reflectance or transmittance.

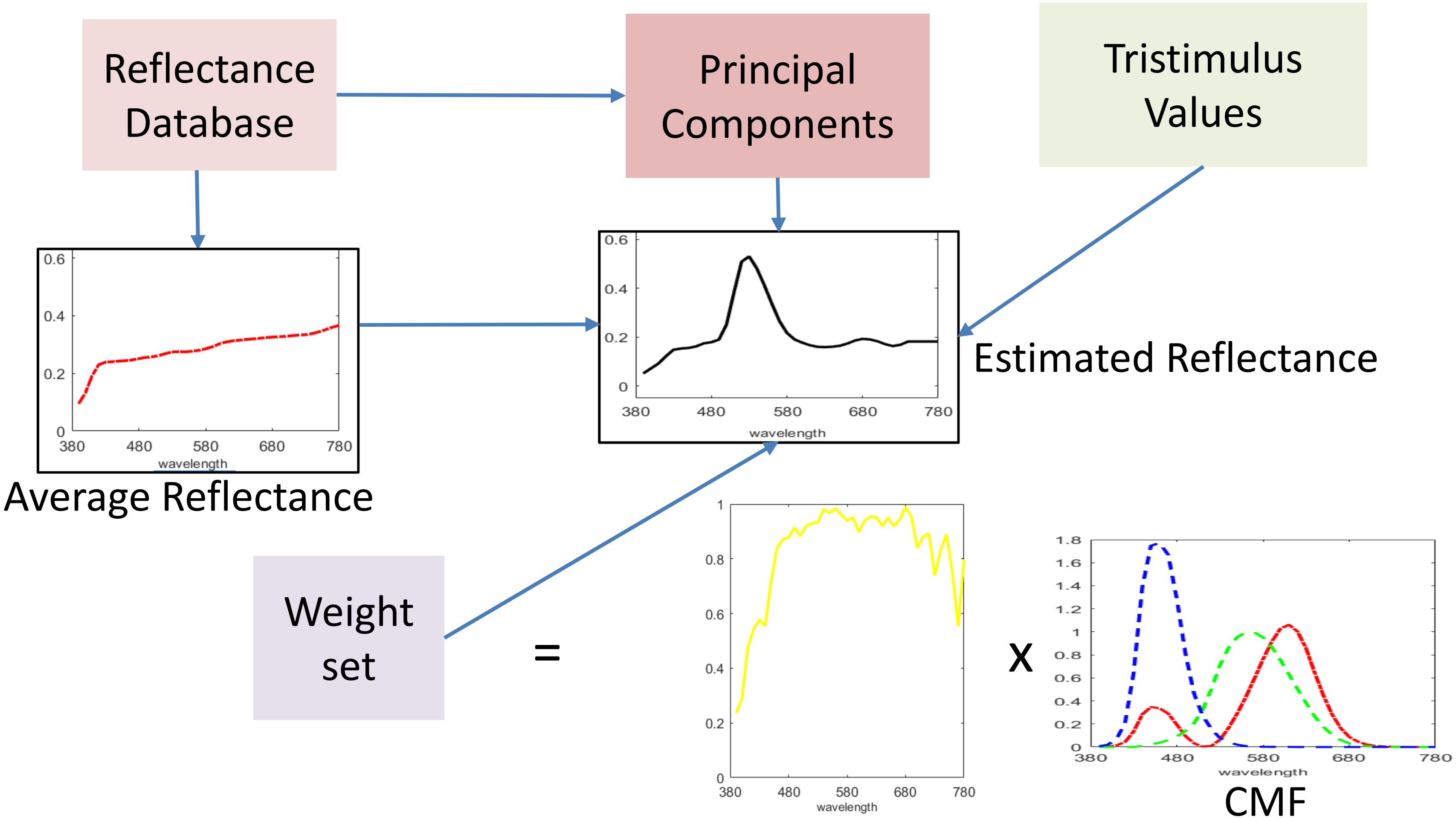


= XYZ

Uses of spectral data

- Calculating colorimetric values
- Understanding the properties of an object independent of the source light or the viewing conditions
- Characterizing a printer with a physical model
- Spectral output of a printer helps avoid metameric matches
- Data hiding (E.g. Hiding watermarks)

Spectral data from tristimulus values



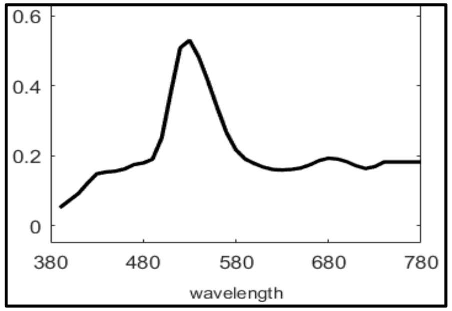
Illuminant

CMF

[Fairman, H. S., & Brill, M. H. (2004).]

Estimated Reflectance

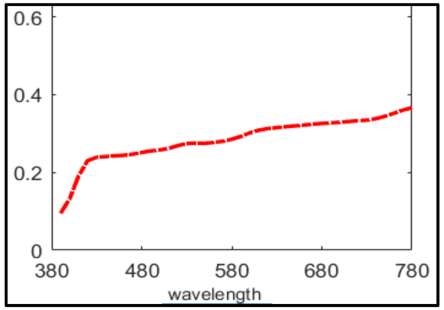
R*



Estimated Reflectance

=

Vo



Average Reflectance of the database

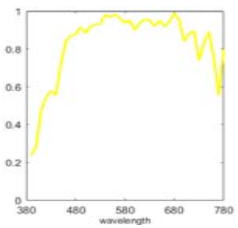
\+ **E** Principal Components X **C** Coefficients

- Principal Components - The K eigenvectors having the highest associated eigenvalues which contain the variance data of the training reflectances.
- Coefficients – PC co-ordinates that weight the columns of E additively to estimate the residual between the original reflectance spectrum and the mean of all reflectance spectra.

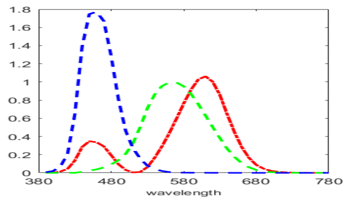
Tristimulus constrained coefficients

- The PC coordinates for estimating reflectance from tristimulus values has to be tristimulus constrained.

$$\mathbf{C = (A^T E)^{-1}(T - T_{avg})}$$

A =


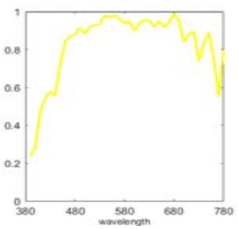
Illuminant

x


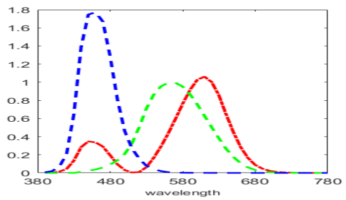
CMF

T = Tristimulus value

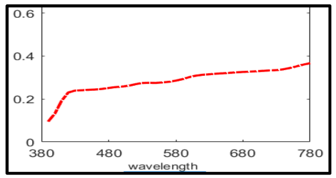
E = Principal Components

T_{avg} =


Illuminant

x


CMF

x


Average Reflectance

Tristimulus value of the average reflectance of the database

Weighted Reflectances

2. Spectral Estimation using weighted PCA [Agahian et. al]

$$d = 1 / ((\Delta E_{2000}(XYZrso\ , XYZt) + 0.01)$$

- $XYZrso$: Computed Using Training Reflectance
- $XYZt$: Test Tristimulus Value
- 0.01: To avoid division by zero

- **Weighted Training Reflectances = $[d_1R_1, d_2R_2, \ldots, d_iR_i]$**

$$R = Eo + E((A^T E)^{-1}(T - A^T Eo))$$

Methods

Dataset 1 → Training set
Dataset 1 → Test set

Dataset 2 → Training set

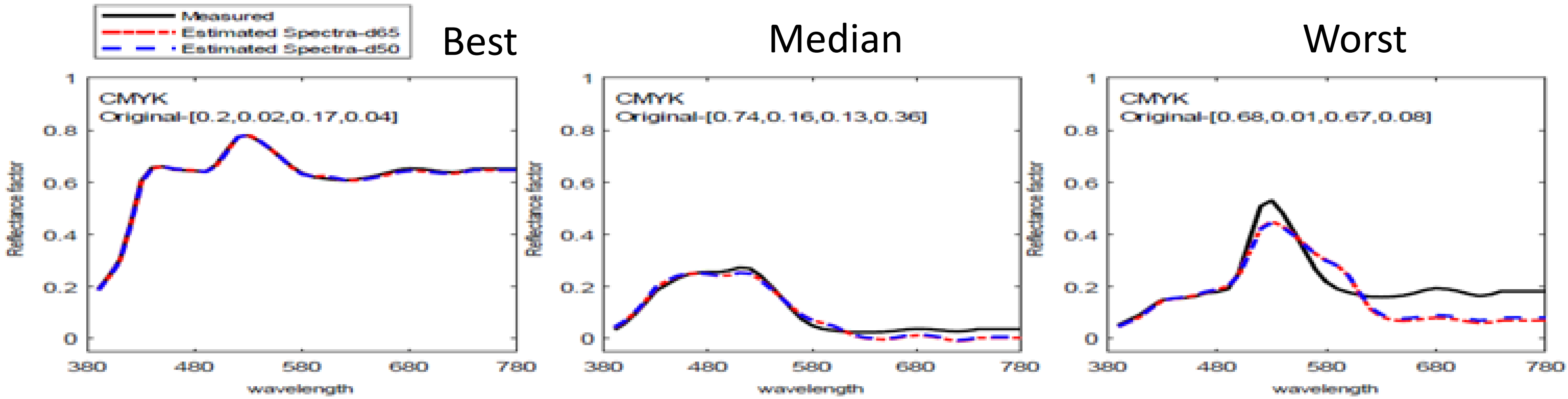
Workflow 1

Training **Dataset 1**
↓
Calculate the Pcs
↓
Estimate reflectance for test Dataset 1
↓
Evaluate against the ground truth for test Dataset 1

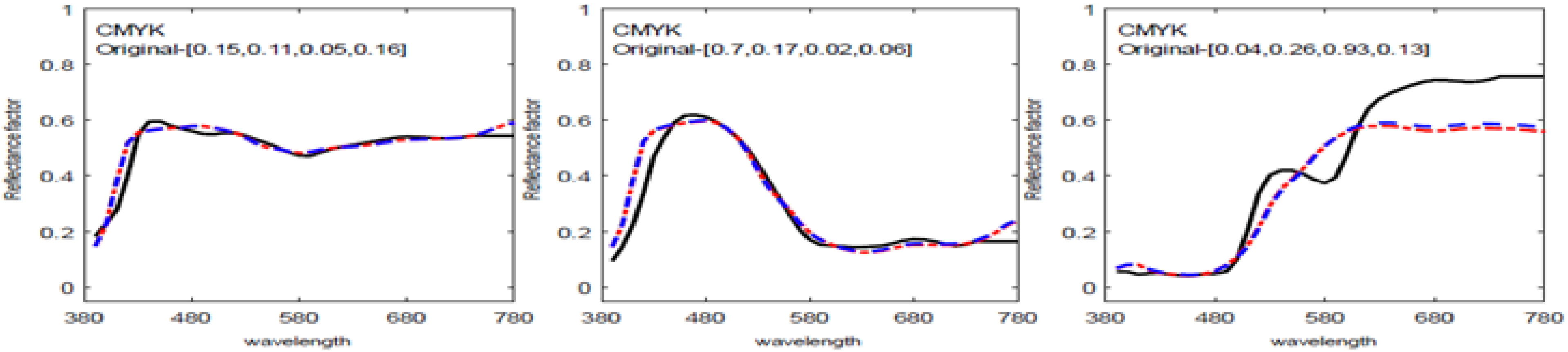
Workflow 2

Training **Dataset 2**
↓
Calculate the Pcs
↓
Estimate reflectance for test Dataset 1
↓
Evaluate against the ground truth for test Dataset 1

Results

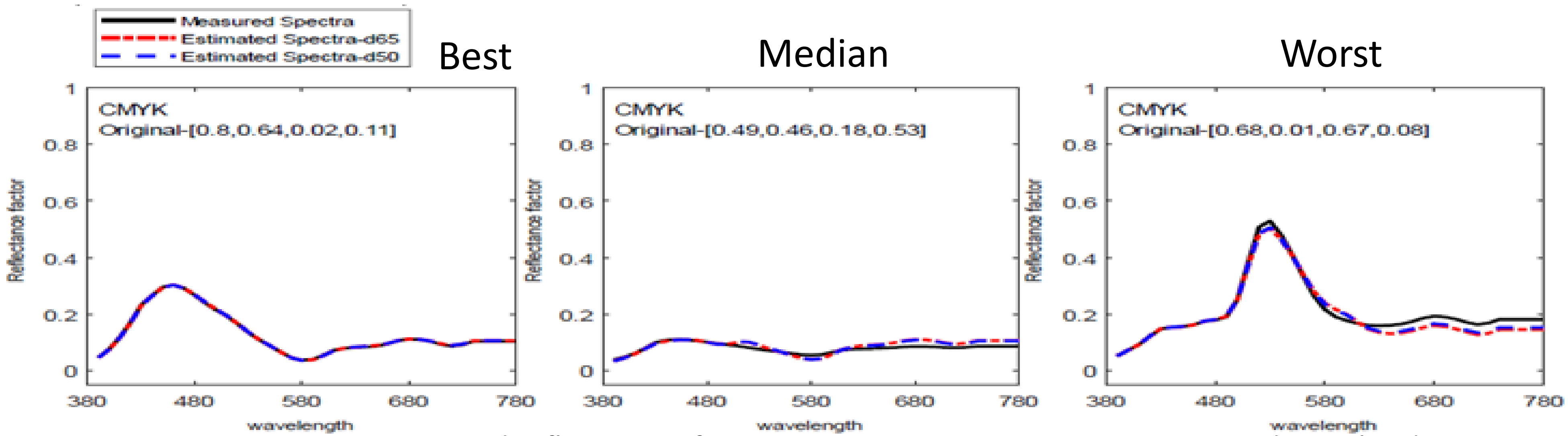


Estimated reflectance of Test Dataset 1 using training Dataset 1 and classical PCA

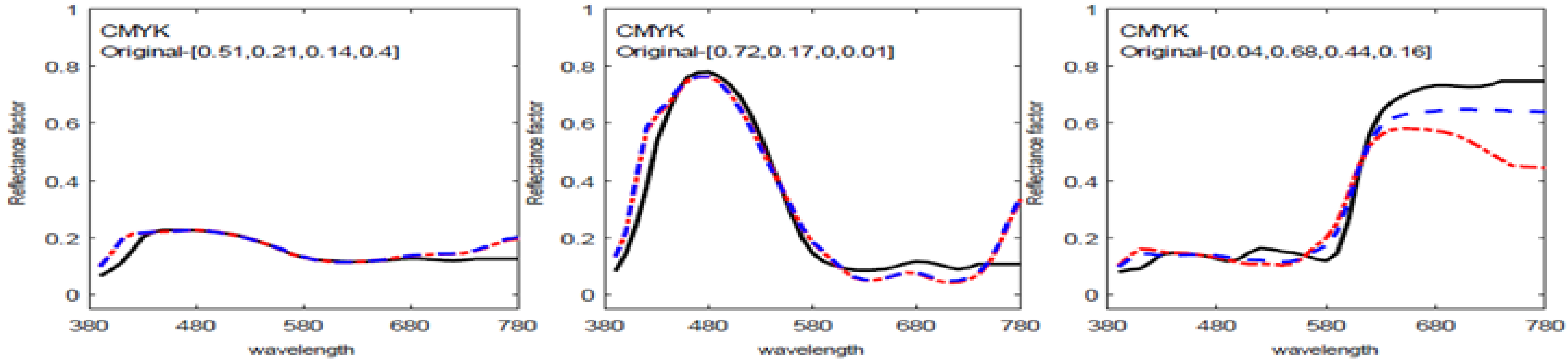


Estimated reflectance of Test Dataset 1 using training Dataset 2 and classical PCA

Results

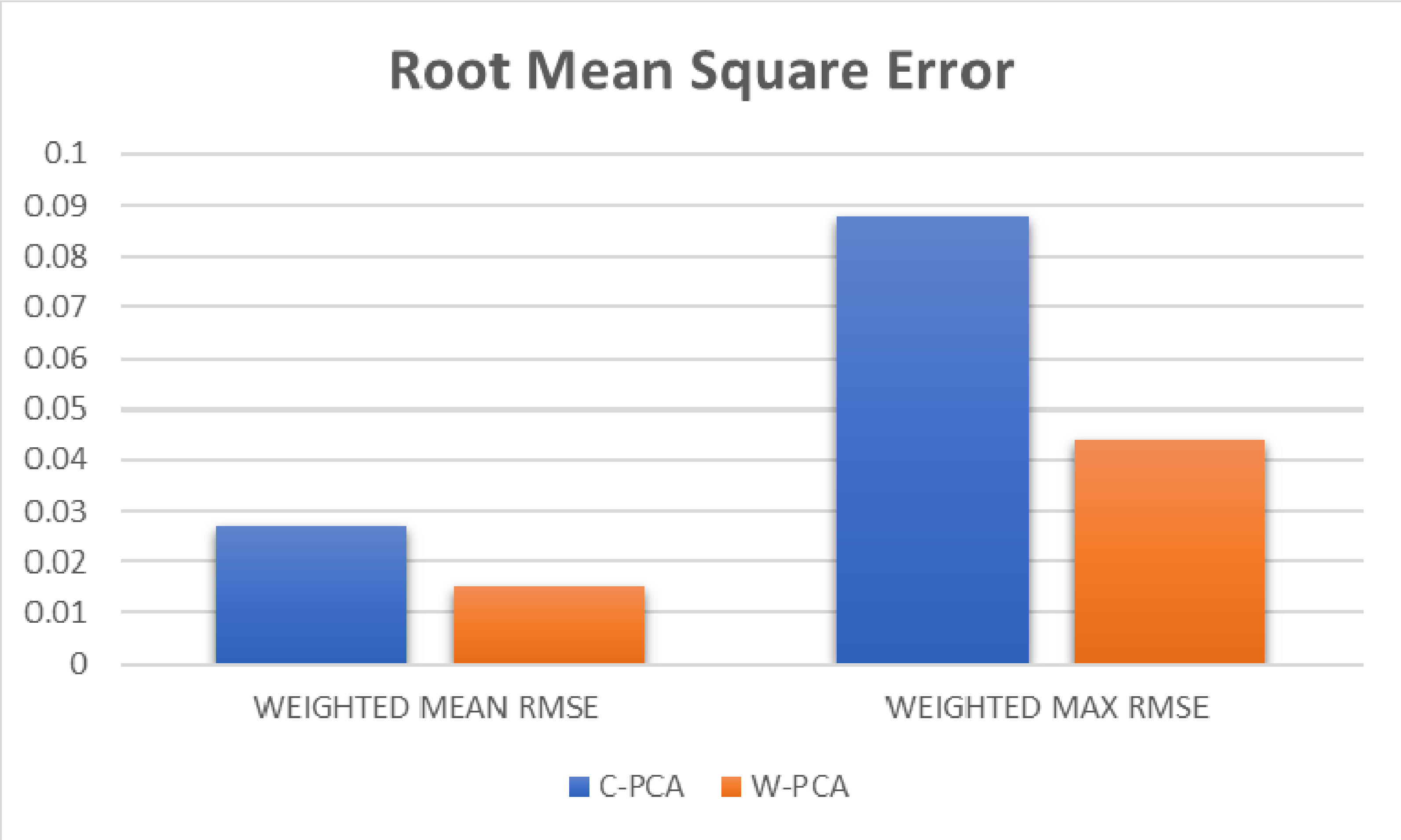


Estimated reflectance of Test Dataset 1 using training Dataset 1 and weighted PCA



Estimated reflectance of Test Dataset 1 using training Dataset 2 and weighted PCA

Analysis


Root Mean Square Error
0.1
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
WEIGHTED MEAN RMSE
WEIGHTED MAX RMSE
C-PCA
W-PCA

Analysis

	WEIGHTED MEAN ΔE00			WEIGHTED MAX ΔE00		
	D65/D50	**D65/C**	**D65/A**	**D65/D50**	**D65/C**	**D65/A**
C-PCA D65	0.55	0.18	1.96	4.44	1.96	12.57
C-PCA D50	0.58	0.17	0.90	5.94	2.51	4.52
W-PCA D65	0.26	0.09	0.94	4.62	1.53	13.84
W-PCA D50	0.18	0.06	0.35	0.84	0.33	1.49

Metamerism Index

Analysis

To increase accuracy of the estimated reflectance

- the illuminant and cmf

chosen should be the same or closer to the illuminant and cmf used in the test XYZ.

Chromatic Adaptation

- Chromatic Adaptation: “Visual process whereby approximate compensation is made for changes in the colors of stimuli, especially in the case of changes in illuminants.” [CIE, e-ILV]

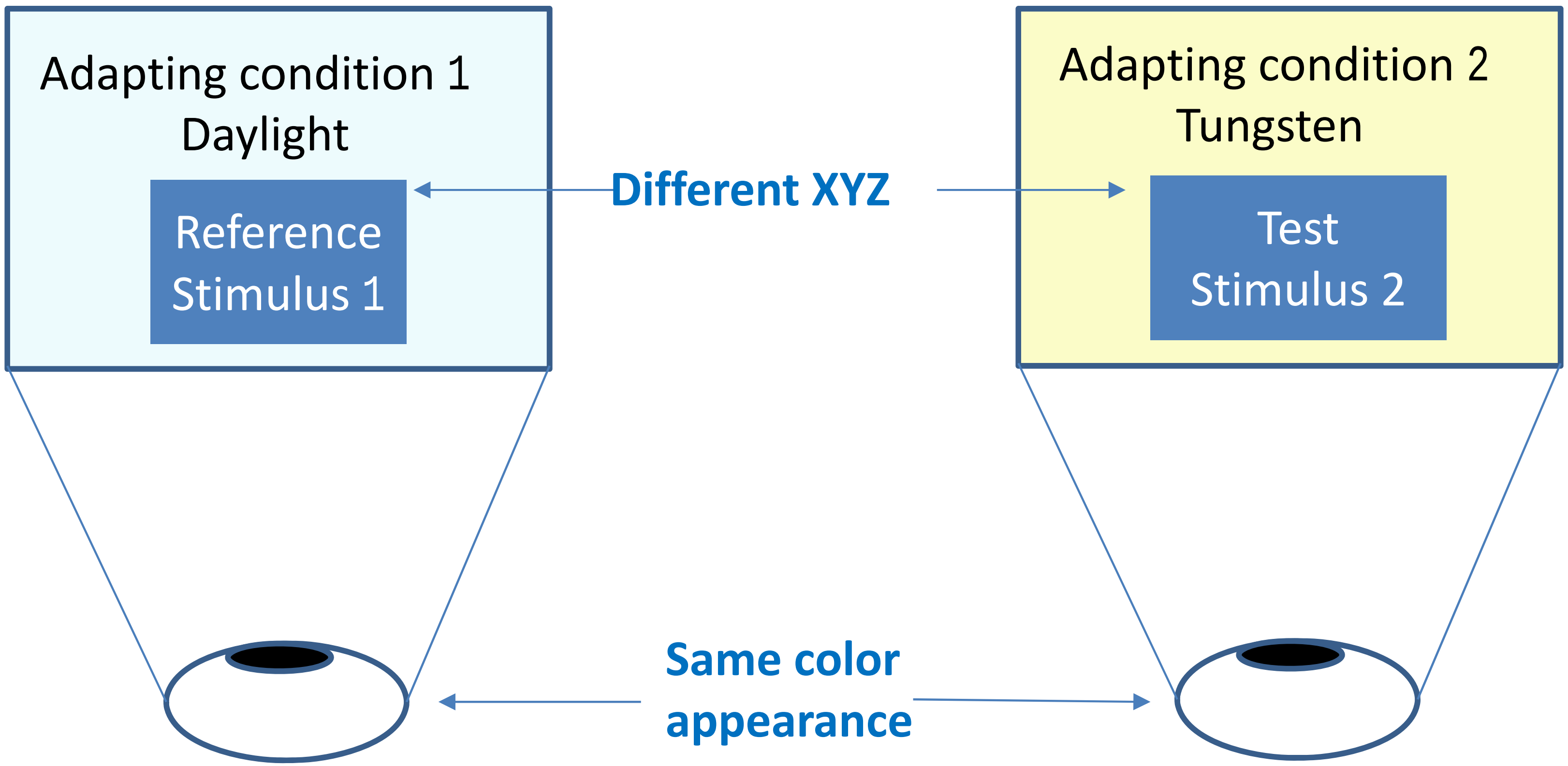
Same scene under different Illuminants


Visual appearance

http://www.psy.ritsumei.ac.jp/~akitaoka/sakkakuWS2019.html

Corresponding colors

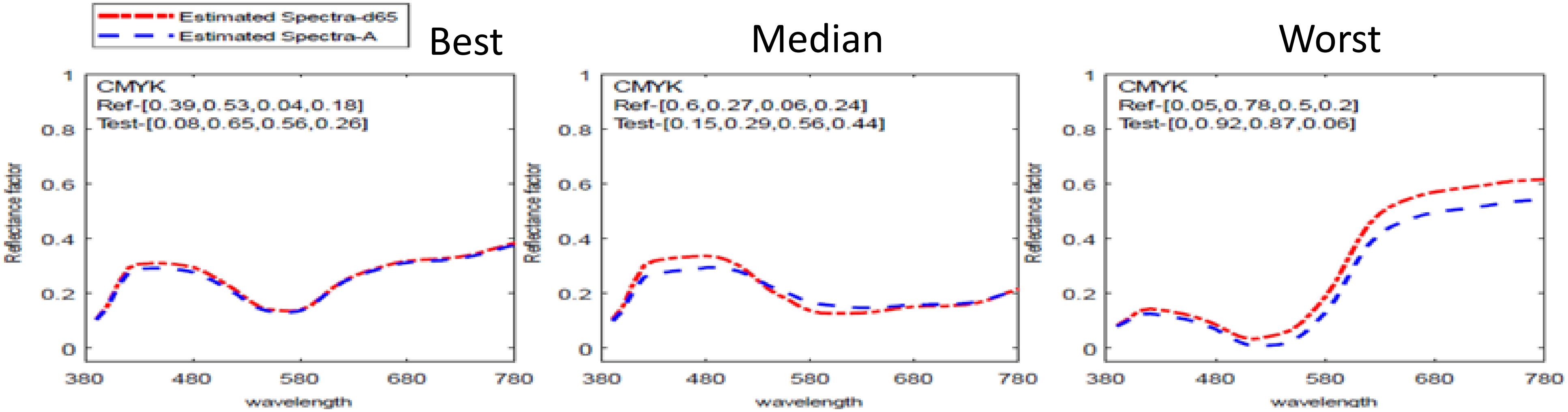
- Corresponding colors: colors that perceptually match under different adapting conditions.



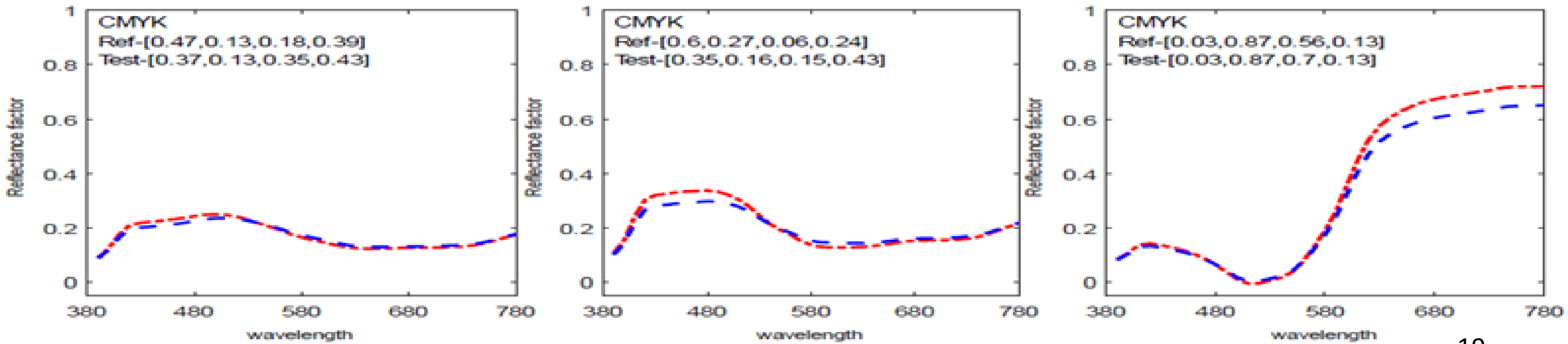
Spectral data of corresponding colors

- Chromatic adaptation transform is performed on XYZ colorimetric data, so spectral data is not available.
- Our goal is to estimate from chromatically adapted XYZ data

Result of Corresponding Color datasets



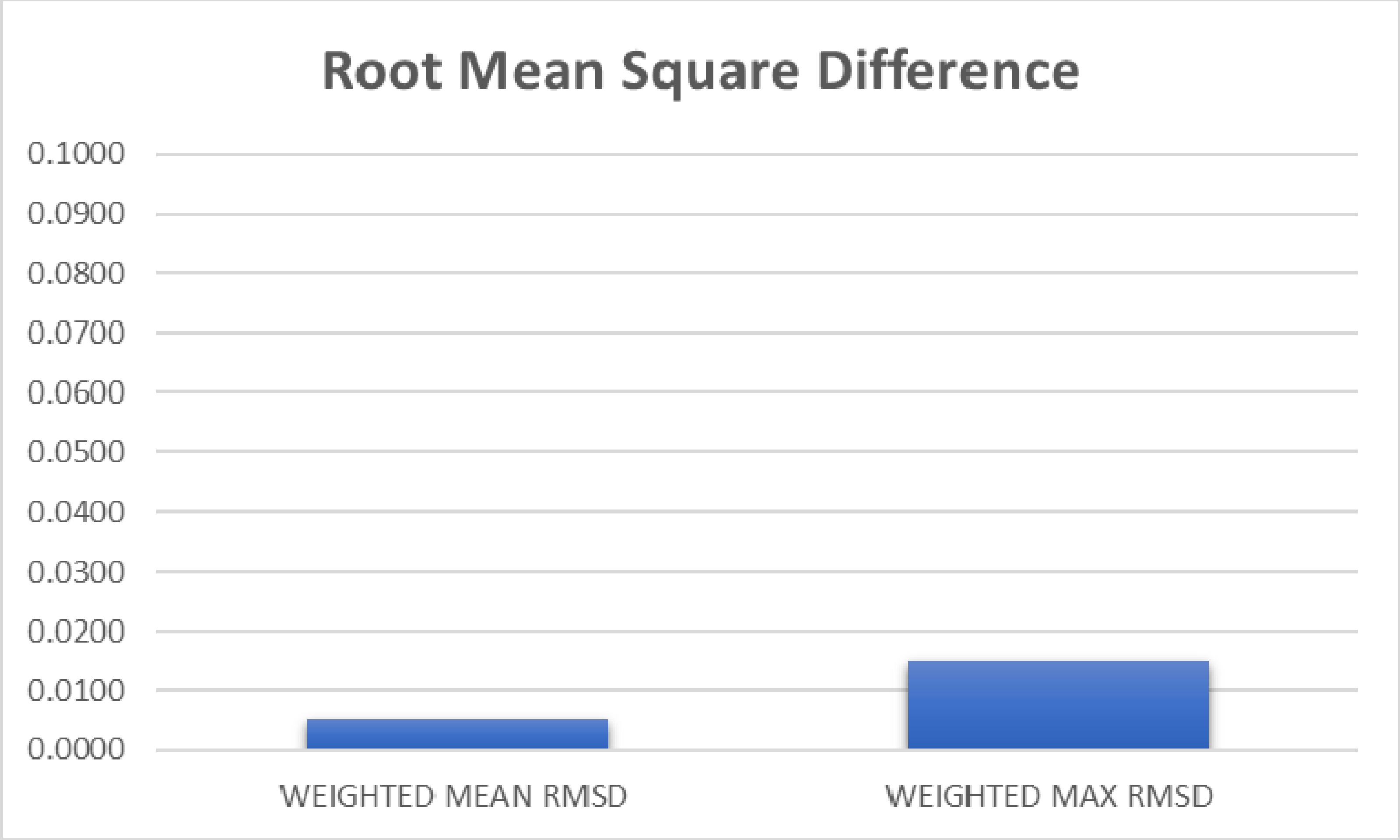
Estimated reflectances of Lutchi (A) using classical PCA



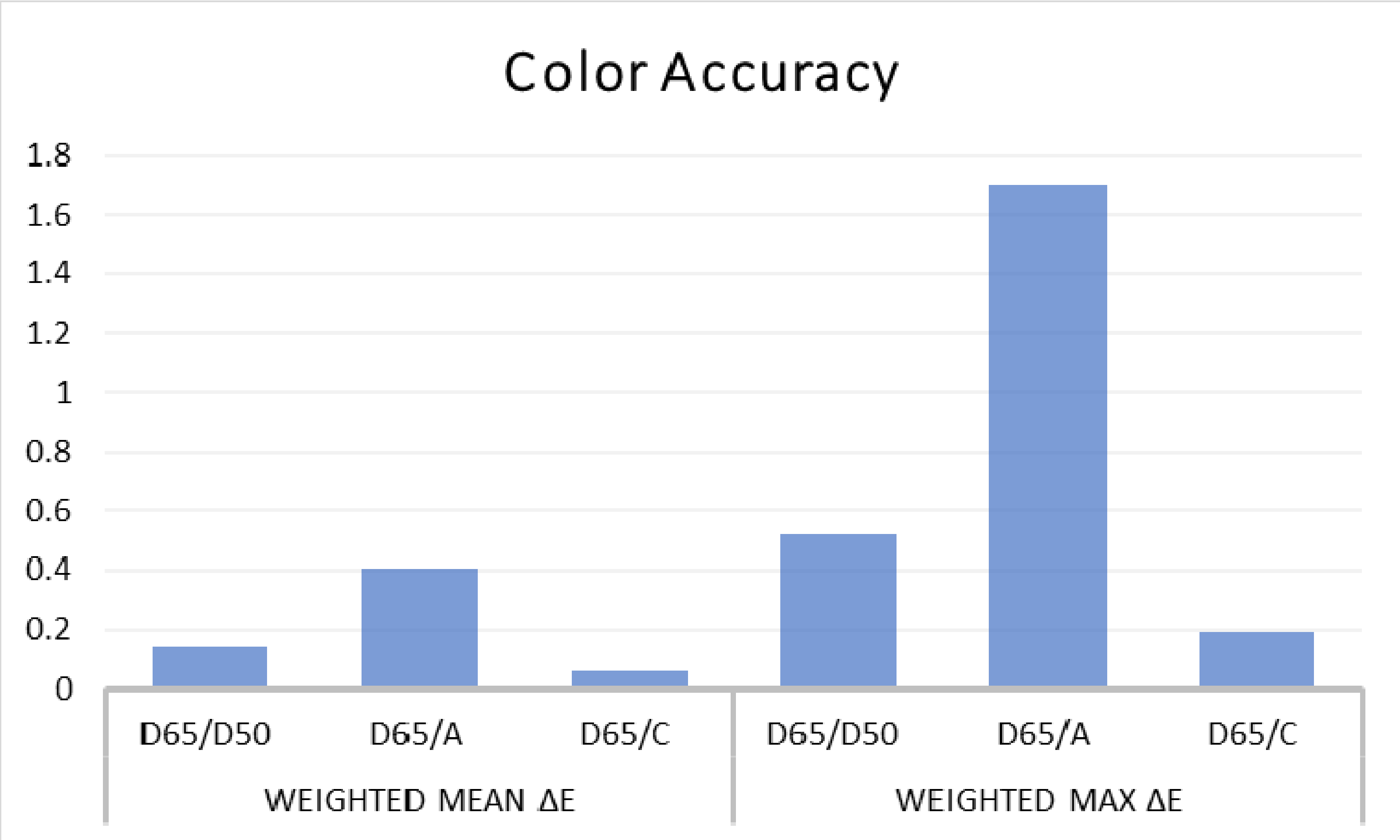
Estimated reflectances of Lutchi (D50) using classical PCA


durst

Analysis


Root Mean Square Difference
0.1000
0.0900
0.0800
0.0700
0.0600
0.0500
0.0400
0.0300
0.0200
0.0100
0.0000
WEIGHTED MEAN RMSD
WEIGHTED MAX RMSD

Analysis


Color Accuracy
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
D65/D50
D65/A
D65/C
D65/D50
D65/A
D65/C
WEIGHTED MEAN ΔE
WEIGHTED MAX ΔE

Conclusion

- Spectral estimation can be done with good performance
- The reflectance database has to be selected carefully and should correspond well to the test material.
- Classical PCA can obtain spectral data from XYZ values efficiently with acceptable metamerism index values.
- Classical PCA is better than Weighted PCA is better but the computation cost is high.
- It is possible to get spectral estimates from chromatically adapted data

Thank you for your attention

Contact information:

Name: Tanzima Habib

E-mail: syedath@ntnu.no

Web: www.colorlab.no