Getting spectral data when you don't have spectral measurements

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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.

\[ \text{Illuminant} \rightarrow \text{Reflectance or transmittance} \]

\[ = \text{XYZ} \]
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

Reflectance Database $\rightarrow$ Principal Components $\rightarrow$ Tristimulus Values

Estimated Reflectance

Average Reflectance

Weight set $=$

Illuminant $\times$ CMF

Estimated Reflectance

\[ R^* = \text{Vo} + \text{Principal Components} \times \text{Coefficients} \]

- 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.

\[ C = (A^T E)^{-1} (T - T_{\text{avg}}) \]

- \( A = \) Illuminant
- \( T_{\text{avg}} = \) Tristimulus value of the average reflectance of the database
- \( T = \) Tristimulus value
- \( E = \) Principal Components

\[ T_{\text{avg}} = \text{Average Reflectance} \]
Weighted Reflectances

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

\[ d = \frac{1}{((\Delta E_{2000}(XYZ_{rso},XYZ_{t}) + 0.01)} \]

Computed Using Training Reflectance

To avoid division by zero

Test Tristimulus Value

- Weighted Training Reflectances = \([d_1R_1, d_2R_2, \ldots, d_iR_i]\)

\[ R = E_0 + E((A^T E)^{-1}(T - A^T E_0)) \]
Methods

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

<table>
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<th>WEIGHTED MEAN RMSE</th>
<th>WEIGHTED MAX RMSE</th>
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<td>C-PCA</td>
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<tr>
<td>W-PCA</td>
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<td>0.10</td>
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Analysis

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<td>D65/C</td>
<td>D65/A</td>
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<td>C-PCA D65</td>
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<td><strong>1.49</strong></td>
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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.

Adapting condition 1
Daylight
Reference Stimulus 1

Different XYZ

Adapting condition 2
Tungsten
Test Stimulus 2

Same color appearance
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

Best

Median

Worst
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

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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

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