The CIECAM02 and Its Newly Derived Uniform Colour Spaces

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Three main applications of Colorimetry

- Colour specification
  - XYZ
- Colour difference evaluation
  - CIELAB, CMC, CIE94, CIEDE2000
- Colour appearance prediction
  - CIECAM97s, CIECAM02

Can a unique colour model to perform all tasks?

Cross-Media Colour Reproduction

Aims

1. To develop uniform colour spaces based upon CIECAM02, the newly adopted CIE colour appearance model.

2. To fit the experimental data sets based upon large and small colour differences.

CIECAM02

Input and output parameters

Brightness (Q)
Lightness (L)
Redness-Greenness (a)
Yellowness-Blueness (b)
Colourfulness (M)
Chroma (C)
Saturation (s)
Hue angle (h)
Hue composition (H)

Surround: Average, Dim and Dark
Cone responses
Dynamic responses
Opponent Process
Achromatic Signal
Appearance attributes
Background, media/surround

Chromatic adaptation
Luminance
R, G, B
J, C, h; Q, M, h?
Uniform colour space
J, C, H; Q, M, H?

X \times Y: \text{X} \times \text{Y} 
\text{XOYOZO} \ \ \ \ \text{X} \ \ \ \ \text{Y} \ \ \ \ \text{Z}

Hue
An area appears to be similar to one of the 4 unitary hues: red, yellow, green and blue, or a combination of two of them.

\text{colour appearance (YSDR)}

Colour difference (0° to 360°).

Different structures for calculating \( \Delta E \)

\[
\Delta E_{Xs} = \sqrt{\Delta J^2 + \Delta a_{Xs}^2 + \Delta h_{Xs}^2}
\]
\[
\Delta E_{Ys} = \sqrt{\Delta J^2 + \Delta a_{Ys}^2 + \Delta h_{Ys}^2}
\]
\[
\Delta E_{M} = \sqrt{\Delta J^2 + \Delta a_{M}^2 + \Delta h_{M}^2}
\]

where

\( a_{Xs} = C \cos(h) \quad \text{and} \quad b_{Xs} = C \sin(h) \)
\( a_{Ys} = M \cos(h) \quad \text{and} \quad b_{Ys} = M \sin(h) \)
\( a_{M} = s \cos(h) \quad \text{and} \quad b_{M} = s \sin(h) \)

Measure of Fit – PF/3

\[
PF/3 = 100(\gamma + CV/100 + V_{AB} - 1)/3
\]

\( CV \): coefficient of variation
\( \gamma \): gamma
\( V_{AB} \): derived by Schultze

For a perfect agreement, \( CV = 0, \gamma = 1 \) and \( V_{AB} = 0 \)

Which attributes to use (in PF/3 units)?

<table>
<thead>
<tr>
<th>Dataset</th>
<th>No. of pairs</th>
<th>( \Delta E_{Xs} )</th>
<th>( \Delta E_{Ys} )</th>
<th>( \Delta E_{M} )</th>
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<tbody>
<tr>
<td>Zhu</td>
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<tr>
<td>SCD</td>
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<td>49</td>
<td>47</td>
<td>78</td>
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</tbody>
</table>

LCD (Large colour-difference): mean of 10.0 \( \Delta E^*_{ab} \) units
SCD (Small colour-difference): mean of 2.5 \( \Delta E^*_{ab} \) units

A simple modification on \( M \) and \( J \)

\[
\Delta E' = \sqrt{\Delta J'^2 + \Delta a'^2 + \Delta h'^2}
\]

where

\( \Delta J' = J'_1 - J'_2, \quad \Delta a' = a'_1 - a'_2, \quad \Delta h' = h'_1 - h'_2 \)

and

\( M' = k_x \times \ln(1 + k_x M_x), \quad M'_2 = k_x \times \ln(1 + k_x M_x) \)

\( a'_1 = M'_1 \cos(h_1), \quad h'_1 = M'_1 \sin(h_1) \)

\( a'_2 = M'_2 \cos(h_2), \quad h'_2 = M'_2 \sin(h_2) \)

\[
J'_1 = \frac{1.7 J_1}{1 + 0.007 J_1}, \quad J'_2 = \frac{1.7 J_2}{1 + 0.007 J_2}
\]
Performance for fitting LCD data

<table>
<thead>
<tr>
<th>Colour spaces</th>
<th>PF/3</th>
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</thead>
<tbody>
<tr>
<td>CIELAB</td>
<td>26</td>
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<tr>
<td>NC_IIIC</td>
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<td>IPT</td>
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<td>GLAB</td>
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<td>OSA</td>
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<td>CIECAM02</td>
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<tr>
<td>CAM02-LCD</td>
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</table>

Performance for fitting SCD data

<table>
<thead>
<tr>
<th>Model</th>
<th>Type</th>
<th>PF/3</th>
</tr>
</thead>
<tbody>
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<tr>
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<td>CIECAM02</td>
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<td>DIN99d</td>
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<td>CAM02-SCD</td>
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<tr>
<td>CIEDE2000</td>
<td>CDE</td>
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</tbody>
</table>

Comparing between CA, LCD and SCD data

Consistent improvement of 2% from $J$ to $J'$

OSA samples

CIELAB, IPT, CAM02-LCD

CIELAB, DIN99d

CIELAB, CAM02-SCD
**BFDA – CDF for illuminant A**

1. Introduced by Luo and Rigg in 1987
2. Developed from BFA

\[
\Delta E(BFDA) = \sqrt{\left(\frac{D_C}{100}\right)^2 + \left(\frac{D_H}{100}\right)^2 + \left(\frac{D_Y}{100}\right)^2}
\]

where:

- \(D_C = 0.0213 (31-0.042 C) + 0.666\)
- \(D_H = D_T (G^2 + 1 - G)\)
- \(T = 0.67: 0.004 \cos(\theta - 29^\circ) + 0.211 \cos(2\theta - 101^\circ) + 0.822 \cos(3\theta - 57^\circ) + 0.056 \cos(4\theta + 129^\circ) - 0.034 \cos(5\theta + 202^\circ)\)
- \(G = \sqrt{C^2 + H^2}\)
- \(L(BFDA) = 54.6 \log(1 + 1.5) - 9.6\)
- \(C = a + b^* + a = 1.67 a^*\)
- \(A = \text{rectan}^* + a\)

**Performance of Colour Difference Formulae**

- CIELAB vs. CAM02-SCD
- Mean A/B = 2.38
- Mean A/B = 1.64

**Performance to fit an Illuminant A data set**

<table>
<thead>
<tr>
<th>Model</th>
<th>PF/3</th>
</tr>
</thead>
<tbody>
<tr>
<td>CIELAB</td>
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<tr>
<td>CIEXC02</td>
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<tr>
<td>DIN99d</td>
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<td>CIAMO2-SCD</td>
<td>32</td>
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<tr>
<td>BFDA</td>
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</table>
Conclusions

- Simple modifications were made to CIECAM02 by fitting the LCD and SCD data sets.
- Two versions, CAM02-LCD and CAM02-SCD were developed for evaluating LCD and SCD data sets respectively.
- The BFD Illuminant A data set was also tested showing the superiority of CAM02-SCD.
- CAM based colour difference formula has a major advantage:
  - Taking into account the change of viewing conditions such as illuminant, luminance, background, surround, etc.