An alternative colour rendering index based on memory colours

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Basic Idea & Theoretical Method
Basic Idea:

Referencing is done to **memory colours* of familiar objects**, not to a reference illuminant!

- **Absolute assessment**
  - No need of reference illuminants!
  - No dependence on correlated colour temperature: test sources with different CCT can be compared.

- More realistic way of evaluating colour rendering.

• (*) Memory colours define the colours that are recalled in association with familiar objects in long-term memory ([Bartleson, 1960](#)).
Method

Investigate *colour acceptance boundaries* of *familiar objects*

- *Test subjects rate acceptability (YES/NO) of a set of apparent object colours:*

  YES / NO

Only a *qualitative measure* for colour rendering based on acceptability of apparent object colour.
Method

- Test subjects rate similarity (on a 5 point scale) of a set of apparent object colours to their memory colour of the object:

Similarity ratings on a 5 point scale as a function of chromatic distance to memory colour.

Quantitative measure for colour rendering.
From similarity ratings to an alternative colour rendering index

- Model pooled similarity ratings by a bivariate Gaussian surface $R(x,y)$:

$$X = \begin{pmatrix} x \\ y \end{pmatrix}; \quad X_c = \begin{pmatrix} a_3 \\ a_4 \end{pmatrix}; \quad \Sigma^{-1} = \begin{bmatrix} a_5 & a_7 \\ a_7 & a_6 \end{bmatrix};$$

$$d^2(x, y) = (X - X_c)^T \cdot \Sigma^{-1} \cdot (X - X_c);$$

$$S(x, y) = \exp \left( -\frac{1}{2} (d^2(x, y)) \right);$$

$$R(x, y) = a_1 + a_2 \cdot S(x, y)$$

- Chromaticity of apparent object colour: $X$

- Centre $X_c = \text{chromaticity of memory colour}$

- Mahalanobis distance $d(x, y) \sim \text{degree of similarity } S(x, y)$

- $a_i$ are fitting parameters:
  - $a_1$ & $a_2$ are used to account for inter observer variability
  - $a_3$ to $a_4$ describe the similarity function $S(x, y)$. 
From similarity ratings to an alternative colour rendering index

- Alternative colour rendering index $S_a$:

  - Calculate for each object $i$:
    1. chromaticity of object rendered by the test source
      » by using the spectral reflectance factors of the object.
    2. Mahalanobis distance $d_i$ to chromaticity of memory colour
    3. **Special colour rendering index**: $S'_i = \exp(-0.5 \times d_i)$
    4. **General colour rendering index**: $S'_a = \text{mean}(S_i)$.
    5. (Rescale indices to CRI levels: $Ra(F1-F12) = a \times S_a(F1-F12) + b$)
Practical
Real versus simulated objects?

- Naturalness has influence on similarity ratings
  (Yendrikhovskii, Blommaert & De Ridder, 1999)

- Colour constancy is greater for surface colours and lights in real scenes than in simulated scenes.
  (Berns & Gorzynski, 1991; Brainard, 1998)

Experiments with real objects!
Illumination box to change apparent object colours

– Special design to mask any illuminant clues!

  a. RGBA LEDs
     » change apparent object colour

  b. Diffusing tunnel:
     » uniform illumination of objects
     » avoid specular reflection on object

  c. Transparent support for objects:
     » hide surface reflections
       revealing illumination colour

  d. Back panel lighting:
     » constant adaptation white with CCT = 5600K.

Create the illusion of the object changing colour!
Spectral Measurements

– Tele-spectroradiometrically:
  • radiometric measuring head
  • 74055 MS260i spectrograph
  • iDUS DV420A-BU2 CCD camera

– Setup identical to viewing conditions
Chromaticities / colour spaces

– CIE 10 degree observer

– Measured chromaticities are transformed to corresponding colours:

  • Chromatic Adaptation Transform: CAT02
  • Illuminant: D65 (for IPT!)

– Colour spaces:

  • CIECAM02 is unfortunately not applicable:
    – Yb of background cannot be defined, because it is more luminous (=self luminous) than the reflected white of the front panel (Yb would be > 100).
      *Personal communication with Mark Fairchild.*

  • IPT (Ebner & Fairchild, 1998): ~ perceptually uniform colour space, especially in hue.
    – Studies have shown that the uniform color space performs as well, and in some case better, as CIECAM02
Test Object Selection

- **High degree of familiarity**: NATURAL OBJECTS (e.g. food)

- Object chromaticity distributions are preferably unimodal or a single mode should be **unambiguously specifiable**; i.e. the natural colour variance should not be too high:

  e.g.:

  • *green apple, ripe banana, …*
  • but NOT: *blue grape*, because the chromaticity of *blue grapes* varies from a black/dark blue to wine red.
Test Object Selection

– Object chromaticities spread uniformly around the hue circle:
  
  • green, yellow: green apple, sliced cucumber, ripe banana, cauliflower
  • red, purple & blue:

  some difficulties:
  
  » Illumination box cannot change the apparent colour of RED natural objects sufficiently due to their highly chromatic nature.

    - ORANGE and strawberry yoghurt is taken as a compromise.

  » Number of blue well-known unambiguously specifiable objects is extremely limited.

    - a SMURF figurine was selected, because when questioned most people report having a good idea smurf blue.

– Special objects: caucasian skin & neutral grey sphere (Munsell N4)
Experiment setup:

1. **Calibrate illumination box:** map XYZ to RGBA DAC input values.
2. Calculate object colour solid.
3. Select *luminance plane* with optimum chromaticity gamut.
4. Calculate RGBA DAC input values resulting in a *uniform grid* in the colour space selected.
5. Add double grid points to illumination sequence.
6. Randomize sequence.
7. Add a set of 20 training points to familiarize observers with the scale.
8. Measure the object spectral radiance.
9. Calculate chromaticities of sequence of apparent object colours
10. Visual assessment of sequence by test subjects:
   » Similarity ratings on a 5 point scale
   » 1: very bad; 2: bad; 3: neutral; 4: good; 5: very good
Experimental results
Model results

• Pooled rating distribution was fitted using MATLAB `lsqcurvefit` function.

• For each object a minimum of 1000 ratings were pooled.
  \(\rightarrow\) A minimum of 10 observers per object times 100 grid points.

• **Goodness-of-fit** to mean ratings of pooled data analysed with **Pearson \(\rho\)** and **RMSE**:

<table>
<thead>
<tr>
<th></th>
<th>Apple</th>
<th>Banana</th>
<th>Orange</th>
<th>Lavender</th>
<th>Smurf</th>
<th>Strawberry yoghurt</th>
<th>Sliced Cucumber</th>
<th>Cauliflower</th>
<th>Caucasian skin</th>
<th>Grey sphere</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>(\rho)</strong></td>
<td>0.96</td>
<td>0.98</td>
<td>0.94</td>
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<td>0.96</td>
<td>0.97</td>
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<td>0.96</td>
</tr>
<tr>
<td><strong>RMSE</strong></td>
<td>0.21</td>
<td>0.20</td>
<td>0.29</td>
<td>0.25</td>
<td>0.23</td>
<td>0.25</td>
<td>0.21</td>
<td>0.22</td>
<td>0.27</td>
<td>0.23</td>
</tr>
</tbody>
</table>
Model results

Kevin Smet – An alternative colour rendering index
Colour rendering evaluation based on memory colours.

- Results -
Rescaling the similarity functions

- Similarity functions are rescaled to the CIE CRI level by a linear transformation calculated using a least squares approach:

\[ y = 4.203x - 215.7 \]

\[ R^2 = 0.981 \]

**Advantage:** Colour rendering scores for old sources are kept nearly the same.
Alternative CRI for 90 lamps

- Lamp spectral radiances: see excel file.
Correlation with visual assessments

- All visual scaling data was kindly provided by Sophie Jost-Boissard

  - The Pearson correlation coefficient between the Thurstone scalings for attractiveness, of nine 3000K (Boissard, 2009) & eight 4000K lamps obtained in a series of visual experiments performed by Sophie Jost-Boissard, and the Memory Colour based index is high: $\rho_{3000K} = 0.97$ (p<0.05) & $\rho_{4000K} = 0.98$ (p<0.05).

  As to not obscure any possible correlation between the visual assessments and the Memory Colour based index, only the special colour rendering indices (apple, banana, orange, strawberry yoghurt, sliced cucumber & cauliflower) have been used in this calculation, since a light source having terrible colour rendering capabilities in the blue to purple region might obscur this correlation.

  - The Pearson correlation has also been calculated between the Thurstone scalings for attractiveness and the CRI and CQS. The Pearson correlation coefficients were:

    $\rho_{\text{CRI,3000K}} = 0.19$ (p=0.46) & $\rho_{\text{CRI,4000K}} = 0.30$ (p=0.63)
    $\rho_{\text{CQS,3000K}} = 0.54$ (p=0.17) & $\rho_{\text{CQS,4000K}} = 0.47$ (p=0.11)

    For the same reason described above, special colour rendering indices 1,2,3,4, 9,10,11,13 & 14 have been used for the CRI, while for the CQS special indices 7-15 were selected.
Planned experiments

- Perform validation experiments with a set of test lamps having low CRI but high visual appreciation and with an object set that is not limited to the green-red region!
References


