Status quo of CIE work on colour rendering indices

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Chiba University, Japan
Chair of the CIE TC1-90 “Colour Fidelity Index”
Importance of color rendering of light sources in imaging industries

- Light sources for viewing surface colours are evaluated by a Color Rendering Index (CRI). ISO TC 130 references CRI calculations in its standards for measurement and viewing, but newer types of illumination now being used, especially LEDs, have created the need to redefine the CRI calculation.
## ISO3664 Viewing Conditions

<table>
<thead>
<tr>
<th>ISO viewing condition</th>
<th>Reference illuminant and chromaticity tolerance</th>
<th>Illuminance / luminance</th>
<th>Colour rendering index (according to CIE 13.3)</th>
<th>Metamerism index (according to ISO 23603)</th>
<th>Illumination uniformity (min:max)</th>
<th>Surround luminous reflectance/ luminance/ illuminance</th>
</tr>
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<tr>
<td>Critical comparison Prints (P1)</td>
<td>CIE Illuminant D50 (0.005)</td>
<td>2 000 lx ± 500 lx (should be ± 250 lx)</td>
<td>General index: □ 90 Special indices for samples 1 to 8: □ 80</td>
<td>Visual: C or better (should be B or better) UV: &lt; 1.5 (should be &lt; 1)</td>
<td>for surfaces up to 1m x 1m □ 0.75 for surfaces greater than 1m x 1m □ 0.6</td>
<td>&lt; 60 % (neutral and matt)</td>
</tr>
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<td>Transparencies Direct viewing (T1)</td>
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<td>Practical appraisal of prints (P2)</td>
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An example of CRI of a white LED

Spectral irradiances of a white LED and the reference daylight illuminant D55

Special color rendering indices

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<th>No.2</th>
<th>No.3</th>
<th>No.4</th>
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<tr>
<td>80</td>
<td>94</td>
<td>92</td>
<td>70</td>
</tr>
<tr>
<td>No.5</td>
<td>No.6</td>
<td>No.7</td>
<td>No.8</td>
</tr>
<tr>
<td>78</td>
<td>85</td>
<td>82</td>
<td>65</td>
</tr>
<tr>
<td>No.9</td>
<td>No.10</td>
<td>No.11</td>
<td>No.12</td>
</tr>
<tr>
<td>13</td>
<td>80</td>
<td>65</td>
<td>56</td>
</tr>
<tr>
<td>No.13</td>
<td>No.14</td>
<td>No.15</td>
<td>Ra</td>
</tr>
<tr>
<td>85</td>
<td>96</td>
<td>78</td>
<td>81</td>
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Average CRI
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To evaluate how the spectral power distribution of daylight simulators coincide with the reference daylights.

Prepare 5 pairs of metamer for the reference illuminant, then calculate the color difference between a pair of metamer.

ISO/CIE specifies 5 pairs of metamer for each of D50, D55, and D65, D75. (ISO 23603:2005, Standard method of assessing the spectral quality of daylight simulators for visual appraisal and measurement of colour)
5 pairs of metamer (D55)
Metamism index

\[ MI_{vis} = \frac{\sum_{i=1}^{5} \Delta E_i}{5} \]
An example of metamism indices

\[ MI_{\text{vis}} = \frac{\sum_{i=1}^{5} \Delta E_i}{5} \]

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<tr>
<th>No.</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>MI_{\text{vis}}</th>
</tr>
</thead>
<tbody>
<tr>
<td>ΔEi</td>
<td>2.43</td>
<td>1.92</td>
<td>2.64</td>
<td>4.65</td>
<td>4.64</td>
<td>3.26</td>
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<td>&lt;0.25</td>
<td>A</td>
</tr>
<tr>
<td>0.25~0.5</td>
<td>B</td>
</tr>
<tr>
<td>0.5~1.0</td>
<td>C</td>
</tr>
<tr>
<td>1.0~2.0</td>
<td>D</td>
</tr>
<tr>
<td>&gt;2.0</td>
<td>E</td>
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Purposes of color rendering

- Color fidelity, color difference
  - Color reproduction in imaging (ISO3664)
  - CIE color rendering index, Ra
  - Metamrism index

- Preference, harmony, memory
  - Showcase lighting, cosmetics, skin color
  - Conspicuity, contrast, colorfulness, memory color

- Color discrimination
  - Visual inspection, color vision test
  - Detection threshold, categorical color, color name
How does CIE manage with color rendering for white light sources?

**TC 1-90**
- Color fidelity, color difference
  - Color reproduction in imaging (ISO3664)
  - CIE color rendering index, Ra
  - Metamrism index

**TC 1-91**
- Preference, harmony, memory
  - Showcase lighting, cosmetics, skin color
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- Color discrimination
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Terms of Reference of new TCs

**TC 1-90: Colour Fidelity Index**

- To evaluate available indices based on colour fidelity for assessing the colour quality of white-light sources with a goal of recommending a single colour fidelity index for industrial use.

**TC 1-91: New Methods for Evaluating the Colour Quality of White-Light Sources**

- To evaluate available new methods for evaluating the colour quality of white-light sources with a goal of recommending methods for industrial use. (Methods based on colour fidelity shall not be included: see TC1-90)
Calculation scheme of CIE CRI

Test illuminant

- Spectral power distribution of test light
- XYZ under test light
- von Kries chromatic adaptation
- XYZ corrected by CA
- U*V*W*

Test sample i (i = 1 ～ 14)

△E_i

Reference illuminant

- Spectral power distribution of reference light
- XYZ under reference light
- U*V*W*

R_i = 100 - 4.6△E_i
R_a = ΣR_i / 8 (i = 1 ～ 8)
CIE-CRI test color samples

1: 7.5R6/4
2: 5Y6/4
3: 5GY6/8
4: 2.5G6/6
5: 10BG6/4
6: 5PB6/8
7: 2.5P6/8
8: 10P8/10
9: 4.5R4/13
10: 5Y8/10
11: 4.5G5/8
12: 3PB3/11
13: 5YR8/4
14: 5GY4/4
15: 1YR6/4
Calculation scheme of nCRI

$R_{a, 2012} = 100 \cdot \left( \frac{2}{e^{k \cdot |\Delta E_{rms}|^{1.5}} + 1} \right)^2$
If $|\lambda - \lambda_{ci}| \geq 125 \text{ nm}$: 

$$R(\lambda) = 0.015$$

If $125 \text{ nm} > |\lambda - \lambda_{ci}| \geq 75 \text{ nm}$: 

$$R(\lambda) = 0.015 + (R_{max,i} - 0.015) \cdot \left(\frac{1}{8750 \text{ nm}^2}\right) \cdot (125 \text{ nm} - |\lambda - \lambda_{ci}|)^2$$

If $75 \text{ nm} > |\lambda - \lambda_{ci}| \geq 25 \text{ nm}$: 

$$R(\lambda) = 0.015 + (R_{max,i} - 0.015) \cdot \left(\frac{8}{7} - \frac{2}{175 \text{ nm}} \cdot |\lambda - \lambda_{ci}|\right)$$

If $25 \text{ nm} > |\lambda - \lambda_{ci}|$: 

$$R(\lambda) = 0.015 + (R_{max,i} - 0.015) \cdot \left[1 - \frac{2}{4375 \text{ nm}^2} \cdot |\lambda - \lambda_{ci}|^2\right]$$

Compression of lightness and colorfulness

\[
\Delta E' = \sqrt{\left(\frac{\Delta J'}{K_L}\right)^2 + \Delta a'^2 + \Delta b'^2}
\]

\[
J' = \frac{(1+100c_1)J}{1+c_1J}
\]

\[
M' = \frac{1}{c_2}\ln\left(1 + c_2M\right)
\]

\[
a' = M'\cos(h), \quad b' = M'\sin(h)
\]
Practical examples

R. Luo, CIE TC1-90 Meeting, April 17, 2013
SPD (Spectral power distribution)
SPD (Spectral power distribution)

**HID**

**Incandescent lamps**
Correlation between nCRI and other color rendering indices (all light sources)
\((a^*, b^*)\) coordinates of test color samples
Correlation between nCRI and other color rendering indices (LED)
Correlation between nCRI and other color rendering indices (FL)
Correlation between nCRI and other color rendering indices (HID)
Work Plan

1. To gather reliable experimental data assessing colour fidelity. Div.1 Meeting 2014

2. To analyze the data by proposed colour fidelity indices. End of 2014

3. To write a report to propose the new CIE CRI. Middle of 2015
TC1-91: New Methods for Evaluating the Colour Quality of White-Light Sources

- Color quality index (CQS)
- Memory color rendering index (MCRI)
- Feeling of contrast index (FCI)
- Categorical color rendering index (CCRI)
- more
- To be discussed
AIC 2015 TOKYO
Color and Image 色と像

Date: 19 – 22 May 2015
Venue: Ochanomizu sola city Convention Center, Tokyo, Japan

Welcome to Tokyo
http://www.aic2015.org