Application of the Color Inconstancy Index for Gonio-Apparent Colors

Prof. Dr. Francisco Miguel Martínez Verdú
Color & Vision Group
University of Alicante (Spain)
Outline

- The GVC-UA Team
  - Resources, capabilities and our network
- Inconstancy Color Index
  - Fundamentals
  - Implementation using BYK-mac and byko-spectra cabinet
  - Results for some gonio-apparent panel sets
- Other current and future RTD projects
- Conclusions
The GVC-UA Team

- Color Science & Technology:
  - Light, Matter, Eye and Visual Perception
  - Measurement, appearance and color matching

- 5 PhD
- 4 Physics
- 1 Industrial Eng.
- 1 Chemical Eng.
- 3 PhD students
- 1 Textile Eng.
- 2 Materials Eng.
Special equipment:

- Tele-spectro-radiometers
  - Colorimetric, photometric and radiometric measurements without contact, and adjusted to the size of the target

- Spectro-fluorimeter

- Multi-angle-spectrophotometers
  - Measurement of color/texture appearance of metallic and iridescent objects
Other RTD services from UA

- **Technical Research Services:**
  - XPS, WDX, FRX, SEM, FT-IR, ATR, Raman, etc
  - Laser Confocal Microscopy
  - Bibliographic resources
    - Journals, normatives (ASTM, etc)

- **Management Services for Technology Transfer & Innovation**
  - Private and public RTD projects
  - Intellectual Property (OAMI)
  - Scientific Park of Alicante
Our general capabilities

- **Spectral and color characterization:**
  - Fluorescent, metallic and iridescent objects
  - Light sources (wLED, luminaires, etc)
  - Optical formulation using dyes and pigments
  - *Customized* color quality and formulation software

- **Coloration of materials**
  - New materials, hybrid nano-pigments, etc

- **Color imaging**
  - Digital color reproduction: **hyperspectral capture**, displays, etc
  - Color/Texture appearance: difference between images
  - Visual appearance simulation of 3-D objects

- **Color and lighting psychology**
Our professional networking

- **Consortium CD6-UPC + GVC-UA**
  - CD6: Centre for Sensors, Instruments and Systems Development (Barcelona)
  - Leader: Dr. Jaume Pujol
  - Project VICSEIM 2012-2014
    - Multi-gonio-hyperspectral imaging system
    - Visual and instrumental correlation of gonio-apparent colors

- **Optics Society of Spain**
  - Committee of Color
  - President: Dr. Francisco Heredia, Secretary: Dr. FM Verdú

- **International relationships: AIC, EOS, etc**
Fundamentals (I):
- Color difference of the same panel $\rho(\lambda)$ simultaneously semi-illuminated by two light sources
  - XYZ ref (D65)
  - XYZ test (unrelated)
  - XYZ ref-test (adapted to D65)

\[ \begin{bmatrix} X \\ Y \\ Z \end{bmatrix} \text{ref-test} \]

\[ \begin{bmatrix} X \\ Y \\ Z \end{bmatrix} \text{ref} \]

\[ E_{\text{test}} = 1000 \text{ lx} \]

\[ E_{\text{ref}} = 1000 \text{ lx} \]

Test light source

D65 as reference
Color Inconstancy Index

- Fundamentals (II): EN ISO 105 - J05:2007
  - CAT02 chromatic adaptation transform
  - ΔE CMC, CMCCON02 index

\[ \rho(\lambda) + D65 \rightarrow XYZ (D65) \rightarrow L^*a^*b^* (D65) \rightarrow \Delta E CMC (1:1) \]

\[ \rho(\lambda) + \text{source test} \rightarrow XYZ (test) \rightarrow \text{CAT02} \rightarrow XYZ \text{ D65-test} \rightarrow L^*a^*b^* \text{ D65-test} \]

- ΔE AUDI2000
- 6 geometries: 45as-15, 45as15, ..., 45as110
Color Inconstancy Index

- Implementation using a BYK-mac and a Byko-spectra effect cabinet:
  - \( \rho(\lambda) \) measured for 6 geometries
  - Simulation installing 2 light sources
  - Color difference (under D65)
Gonio-apparent panel sets:

- 18 WRC panels, with some Xirallic-type pigments + 1 solid (blue-green) pigment
- 56 BASF Coatings panels, with proprietary color recipes
- 117 AUDI panels, with proprietary color recipes
Color Inconstancy Index

- Test light sources: byko (BSE), wLED, F11, A
  - Normalized spectra for 1000 lx of illuminance level
Color Inconstancy Index: results

- WRC panel set: $\Delta E_{Audi2000} = CON$ index

**Color Travel:** m1 Iriodin 9103 100%

**Color Travel:** m10 BG 80 9103 10 MS 10 %

<table>
<thead>
<tr>
<th></th>
<th>45as-15</th>
<th>45as15</th>
<th>45as25</th>
<th>45as45</th>
<th>45as75</th>
<th>45as110</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\Delta E_{\text{max}}$</td>
<td>3.49</td>
<td>3.50</td>
<td>4.44</td>
<td>3.38</td>
<td>3.21</td>
<td>3.26</td>
</tr>
<tr>
<td>$\Delta E_{\text{min}}$</td>
<td>0.58</td>
<td>0.68</td>
<td>0.94</td>
<td>1.25</td>
<td>1.58</td>
<td>1.47</td>
</tr>
<tr>
<td>Average</td>
<td>1.53</td>
<td>1.60</td>
<td>2.53</td>
<td>2.25</td>
<td>2.19</td>
<td>2.05</td>
</tr>
</tbody>
</table>
Color Inconstancy Index: results

- BASF panel set:
  - Gamuts in CIELAB for BSE vs. wLED and F11 vs. A
# Color Inconstancy Index: results

- **BASF panel set: $\Delta E$ AUDI2000 = CON index**

<table>
<thead>
<tr>
<th></th>
<th>45as-15</th>
<th>45as15</th>
<th>45as25</th>
<th>45as45</th>
<th>45as75</th>
<th>45as110</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>$\Delta E_{max}$</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>F11 vs. D65</td>
<td>23.94</td>
<td>27.25</td>
<td>26.48</td>
<td>26.19</td>
<td>22.02</td>
<td>23.60</td>
</tr>
<tr>
<td><strong>$\Delta E_{min}$</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>1.58</td>
<td>1.03</td>
<td>0.44</td>
<td>0.69</td>
<td>0.58</td>
<td>0.47</td>
</tr>
<tr>
<td><strong>Average</strong></td>
<td>5.33</td>
<td>5.98</td>
<td>5.00</td>
<td>4.60</td>
<td>3.51</td>
<td>3.54</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>45as-15</th>
<th>45as15</th>
<th>45as25</th>
<th>45as45</th>
<th>45as75</th>
<th>45as110</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>$\Delta E_{max}$</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>wLED vs. D65</td>
<td>34.87</td>
<td>35.25</td>
<td>35.59</td>
<td>39.32</td>
<td>33.62</td>
<td>33.58</td>
</tr>
<tr>
<td><strong>$\Delta E_{min}$</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>1.47</td>
<td>0.83</td>
<td>0.76</td>
<td>0.09</td>
<td>0.08</td>
<td>0.09</td>
</tr>
<tr>
<td><strong>Average</strong></td>
<td>8.88</td>
<td>9.53</td>
<td>8.77</td>
<td>8.75</td>
<td>7.21</td>
<td>7.32</td>
</tr>
</tbody>
</table>
# Color Inconstancy Index: results

- **AUDI panel set:** \( \Delta E \) AUDI2000 = CON index

## Color Travel: m48 Sepangblau

![Graph](image1)

<table>
<thead>
<tr>
<th>BSE vs. D65</th>
<th>45as-15</th>
<th>45as15</th>
<th>45as25</th>
<th>45as45</th>
<th>45as75</th>
<th>45as110</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \Delta E_{\text{max}} )</td>
<td>17.43</td>
<td>16.62</td>
<td>13.89</td>
<td>11.82</td>
<td>12.19</td>
<td>13.48</td>
</tr>
<tr>
<td>( \Delta E_{\text{min}} )</td>
<td>0.24</td>
<td>0.23</td>
<td>0.27</td>
<td>0.14</td>
<td>0.15</td>
<td>0.16</td>
</tr>
<tr>
<td>Average</td>
<td>4.43</td>
<td>4.32</td>
<td>3.85</td>
<td>2.43</td>
<td>2.16</td>
<td>2.25</td>
</tr>
</tbody>
</table>

10th BYK-Gardner User Meeting
## Color Inconstancy Index: results

- **AUDI panel set: \( \Delta E \) AUDI2000 = CON index**

<table>
<thead>
<tr>
<th>F11 vs. D65</th>
<th>45as-15</th>
<th>45as15</th>
<th>45as25</th>
<th>45as45</th>
<th>45as75</th>
<th>45as110</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \Delta E_{\text{max}} )</td>
<td>33.62</td>
<td>32.47</td>
<td>26.67</td>
<td>22.51</td>
<td>23.48</td>
<td>26.26</td>
</tr>
<tr>
<td>( \Delta E_{\text{min}} )</td>
<td>0.53</td>
<td>0.51</td>
<td>0.55</td>
<td>0.28</td>
<td>0.35</td>
<td>0.37</td>
</tr>
<tr>
<td>Average</td>
<td>9.09</td>
<td>8.83</td>
<td>7.86</td>
<td>4.92</td>
<td>4.28</td>
<td>4.45</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>wLED vs. D65</th>
<th>45as-15</th>
<th>45as15</th>
<th>45as25</th>
<th>45as45</th>
<th>45as75</th>
<th>45as110</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \Delta E_{\text{max}} )</td>
<td>65.68</td>
<td>62.40</td>
<td>51.16</td>
<td>36.52</td>
<td>37.82</td>
<td>41.48</td>
</tr>
<tr>
<td>( \Delta E_{\text{min}} )</td>
<td>0.65</td>
<td>0.64</td>
<td>0.62</td>
<td>0.36</td>
<td>0.33</td>
<td>0.33</td>
</tr>
<tr>
<td>Average</td>
<td>14.79</td>
<td>14.27</td>
<td>12.58</td>
<td>8.30</td>
<td>8.01</td>
<td>8.42</td>
</tr>
</tbody>
</table>
Color Inconstancy Index: results

- AUDI panel set: CIELAB partial deviations under BSE

- Graph showing color constancy results with different shading patterns for 45as45 DL*, 45 DC*, and 45 DH*.

10th BYK-Gardner User Meeting
Color Inconstancy Index: results

- AUDI panel set: spectral vs. color analysis

  - Main contribution of $\Delta L^*$, $\Delta C^*$, $\Delta H^*$ for $\Delta E_{ab}$:
    - A: $\Delta C^* > \Delta H^* > \Delta L^*$, except for the “reds” ($\Delta C^* > \Delta L^* > \Delta H^*$)
    - F11: $\Delta H^* > \Delta C^* > \Delta L^*$, except for the “grays” ($\Delta C^* > \Delta H^* > \Delta L^*$)
    - BSE: $\Delta H^* > \Delta C^* > \Delta L^*$, except for the “grays” ($\Delta C^* > \Delta H^* > \Delta L^*$)
    - wLED: $\Delta H^* \approx \Delta C^* >> \Delta L^*$, except for the “blues” ($\Delta H^* > \Delta C^* >> \Delta L^*$)
The spectral content of the light source clearly influences on the CON index of a color panel
- BSE light source keeps the color appearance under D65 of the gonio-apparent panels
  - Pending to test the visual correlation in instrumentally (BYK-mac) approved gonio-apparent pairs
- In contrast, A, F11 and wLED provide different color travels for many gonio-apparent panels

Spectral reflectances with low $C_{ab}^*$ and $L^*$ provide minimum CON index. Example: “Brilliantschwarz”

Spectral reflectances with high $C_{ab}^*$ and middle $L^*$ provide maximum CON index. Example: “Sepangblau”

Depending on industrial application, the CON index for each color recipe (design) can be previously analyzed
- Maximum CON indexes for near-aspecular geometries
Other current and future RTD projects

- JRP IND52 (xD-Reflect) project by EU funds, 2013-16
  - Consortium: CNAM, PTB, CSIC, MIKES, CMI, INRIM, SP, etc

  - Mission and work plan:
    - Meet demands from industry
      - improvement of metrology and measurements capabilities for multidimensional reflectometry
      - understanding of correlation between visual appearance and surface structure
    - Strengthen of European industries’ global competitiveness by:
      - developing metrological and measurement capabilities
      - underpinning and supporting the quality management systems

  - Role of the GVC-UA:
    - WP1: goniochromatism (leader: PTB)
    - WP3: fluorescence (leader: MIKES)
    - WP4: modeling and data analysis (leader: PTB)
    - WP5: visual perception (color, sparkle, etc) (leader: INRIM)
    - WP6: creating impact (leader: CMI)
¡¡ Count on us !!

http://web.ua.es/en/gvc

verdu@ua.es

MASTER in COLOR TECHNOLOGY for the AUTOMOTIVE SECTOR
UNIVERSITY OF ALICANTE