PERCEPTIE VAN DE HELDERHEID VAN LICHTBRONNEN

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Light&Lighting Laboratory
The team
Lighting

Optical design

Measurement Facilities

Appearance

Perception

New Light Sources
Introduction: Colour and Numbers

Stimulus

Light source

Object

\[ E_{e,\lambda}(\lambda) \]

Reflectance

Spectral radiance

\[ L_{e,\lambda}(\lambda) \]
From spectral radiance to tristimulus values \((X,Y,Z)\)

\[
X = k \sum L_{e,\lambda}(\lambda).\bar{X}(\lambda)
\]

\[
Y = k \sum L_{e,\lambda}(\lambda).\bar{Y}(\lambda)
\]

\[
Z = k \sum L_{e,\lambda}(\lambda).\bar{Z}(\lambda)
\]
From tristimulus values \((X,Y,Z)\) to colour coordinates:

\[(x, y) + L\] 

\[(u', v') + L\]
Disadvantages of colour coordinates

- Not uniform with respect to colour differences
- Not directly related to perceptual quantities: hue, saturation, brightness
- Not considering background and surround
(X,Y,Z) or (x,y,L) is the typical colorimetric output for a single stimulus.

Visual perception is however strongly determined by the characteristics of stimulus and environment: related colours.
Colour appearance models CAM generate perceptual correlates of stimuli in relation to background and surround: brightness (lightness), hue, colourfulness (chroma, saturation)

CIECAM02 is an accepted CAM, mimicking some processes in the retina
Colorimetry
CIECAM02

- Chromatic adaptation
- Cone response
- Surround induction

Sample
$X, Y, Z$

CIECAM02 Model

White
$X_w, Y_w, Z_w$

Background
$L_A$

Surround
Avg, dim, dark

Correlates of:
- redness/greenness, $a$
- yellowness/blueness, $b$
- brightness, $Q$
- lightness, $J$
- colourfulness, $M$
- chroma, $C$
- saturation, $s$
- hue angle, $h$
- hue composition, $H$
Colour
Compression and adaptation

\[ \rho_a = g \cdot \frac{I^n}{I^n + I_{1/2}^n} \]
**Colorimetry**

**Effect of Background**

L = 60  
J = 70

L = 60  
J = 73

L = 60  
J = 80

- White background
- Medium gray background
- Black background
Perception of light sources
Two categories

Dark background

Luminous background

CAM available?
Dark background

5 years ago: three Colour Appearance Models

- CAM97u (Hunt, 1997)
- ATD01 (Guth, 2002)
- CAMFu (Fu, 2012)
- L_{Eq} (CIE, 2011)
- L_{Eq} Nayatani (2 versions, 1997)

Low correspondence to our experimental data for the brightness of coloured stimuli due to an underestimation of the Helmholtz-Kohlrausch effect

H-K: brightness perception increases with saturation
Luminous background

No model available!

- Traffic signals
- Display (smartphone, billboards)
- Glare
Part 1: can we improve the actual CAMs for a dark background?

Part 2: can we develop a new CAM for a luminous background?
Part 1: experimental Stimuli

- RGBW module, 10° FOV
- 105 + 52 stimuli
- 6 cd/m² < L₁₀ < 297 cd/m² (photopic/glare)
- Dark background
- Chromaticity range:
Selection
• 9 + 11 observers, aged 21 to 32
• Laypersons

Q&A
• Brightness compared to reference (temporal juxtaposition)
• Amount of white versus colour in %
• Relative amount of two unique hues
• Magnitude estimation

Intra- and inter-observer variability
• CV Hue: 10 to 11 %
• CV Brightness: 14 to 20 %
• CV Amount of white: 30 to 44%
Reference brightness: value of 50
0 = no brightness
Part 1: experimental
Psychophysics

Brightness?
Part 1: experimental
Psychophysics

Brightness 50 -> answer
Part 1: experimental Helmholtz-Kohlrausch

60 cd/m²

218 cd/m²

CAM97u
Building a new model: CAM15u
CAM15u: building the model

Step 1: absolute cone excitations

\[ \rho_{10} = 666.7 \int_{390}^{830} L_{e,\lambda}(\lambda) \bar{I}_{10}(\lambda) \, d\lambda \]

\[ \gamma_{10} = 782.3 \int_{390}^{830} L_{e,\lambda}(\lambda) \bar{m}_{10}(\lambda) \, d\lambda \]

\[ \beta_{10} = 1444.6 \int_{390}^{830} L_{e,\lambda}(\lambda) \bar{s}_{10}(\lambda) \, d\lambda \]

- Absolute spectral radiance
- CIE 2006 cone fundamentals (10°)
- Normalization constants
CAM15u: building the model
Step 2: cone compression

\[ \rho_c = \rho_{10}^{1/3} \]
\[ \gamma_c = \gamma_{10}^{1/3} \]
\[ \beta_c = \beta_{10}^{1/3} \]

- Power law
- Power value: determined from observer brightness data of neutral stimuli
Step 3: neural signals

Achromatic signal

$$A = 3.22 \left( 2\rho_c + \gamma_c + \frac{1}{20} \beta_c \right)$$

Red-green balance

$$a = 1\left( \rho_c - \frac{12}{11} \gamma_c + \frac{\beta_c}{11} \right)$$

Yellow-blue balance

$$b = 0.117(\rho_c + \gamma_c - 2\beta_c)$$
Step 4: hue, colourfulness, brightness, saturation, amount of white

Hue \( h = \frac{180}{\pi} \tan^{-1}(b/a) \)

Colourfulness \( M = 135.52 \times \sqrt{a^2 + b^2} \)

Brightness \( Q = A + 2.559 \times M^{0.561} \)

Saturation \( s = \frac{M}{Q} \)

Amount of white \( W = \frac{100}{1 + 2.29 \times s^{2.68}} \)
New validation data set of 52 mixed chromatic and achromatic stimuli; magnitude estimation

CAM15u: performance

Hue, brightness, amount of white

<table>
<thead>
<tr>
<th></th>
<th>Brightness</th>
<th></th>
<th>Hue</th>
<th>Amount of white</th>
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<tr>
<td></td>
<td>R²</td>
<td>r_s</td>
<td>CV</td>
<td>R²</td>
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<td>26</td>
<td>0.99</td>
</tr>
</tbody>
</table>
European Standard for VMS (CEN, 2014) prescribes hue dependent maximum luminance values in dark viewing conditions (circles)
Perception of light sources
State-of-the-art

Dark background

Luminous background
Part 1: can we improve the actual CAMs for a dark background?

Part 2: can we develop a new CAM for a luminous background?
• 6 hues x 5 = 30 stimuli, 10° FOV
• $L_{10} = 50 \text{ cd/m}^2$ (positive contrast)
• Background: $L_{10} = 28 \text{ cd/m}^2$
  
  $\text{CCT= 3880 K}$
  
  70° FOV
• 12 + 10 observers, aged 20 to 50
• Graphical response sheet
Helmholtz-Kohlrausch is even important when a luminous background is present.
Impact of the (neutral) background on the brightness perception (red stimulus, 125 cd/m²)

Mean CV_{inter} R = 16.9

Negative contrast
Development of a new CAM for self-luminous stimuli and background

- First preliminary results (one fixed stimulus)
- Helmholtz-Kohlrausch effect is still important
- Positive and negative contrast: impact on brightness
- Modelling: in progress


Ready-to-use code available:

www.github.com/ksmet1977/CAM15u

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Thank you!
Questions?