The Case for Instrumental Color Tolerancing

ROY S. BERNS

Munsell Color Science Laboratory
Chester F. Carlson Center for Imaging Science
Rochester Institute of Technology
54 Lomb Memorial Drive
Rochester, New York 14623-5604
berns@cis.rit.edu
This talk was presented at a meeting of the Detroit Color Council on June 10, 1997 in Dearborn, Michigan. The theme for this meeting was color measurement and control of automotive materials. This presentation was supported by the Detroit Color Council.
Outline of Presentation

• Introduction
• Data Bases
• Visualization of Systematic Trends
• Model Development
• Model Optimization
• Conclusions
Two Competing Philosophies:

Visual

Instrumental
A Case for Instrumental QA

Prerequisites
- Statistical sampling of batch
- Precise and accurate instrument

Presentation Outline
- Limitations of CIELAB
- Review of CMC and CIE94
- Observer uncertainty
- Recommendations
1973 Meeting of Colorimetry Committee

City University, London

Ganz

MacAdam

Robertson

Wyszecki
"Pending the development of an improved coordinate system..." (CIE Pub. 15.2)

875 color-difference pairs judged by 50 observers (43,750 judgements)
Systematic Limitations in CIELAB

Color difference pairs with the same visual difference had $\Delta E^*$ values that depended on the $C^*_a b^*$ of the standard

$\Delta E = \left[ \Delta L^2 + \left( \frac{\Delta C}{1 + 0.02C} \right)^2 + \Delta H^2 \right]^{1/2}$

McDonald, 1974

$S_c$ vs $C^*_a b^*$
Society of Dyers and Colourists, 1984: CMC

\[ \Delta E_{\text{CMC}(\ell:c)} = CF \left[ \left( \frac{\Delta L^*}{I S_L} \right)^2 + \left( \frac{\Delta C^*_{ab}}{c S_C} \right)^2 + \left( \frac{\Delta H^*_{ab}}{S_H} \right)^2 \right]^{1/2} \]
CIE Division 1 Meeting: Buenos Aires, 1989

TC 1-27 Color differences - soft copy & hard copy

TC 1-28 Parametric factors

TC 1-29 Industrial color difference equation
TC 1-29 Philosophy

Continuous improvement
Applicable to all industries
Statistical validity
Timely results

\[ \Delta E_{TC1-29}^* = \left[ \left( \frac{\Delta L^*}{k_L S_L} \right)^2 + \left( \frac{\Delta C_{ab}^*}{k_C S_C} \right)^2 + \left( \frac{\Delta H_{ab}^*}{k_H S_H} \right)^2 \right]^{1/2} \]

k = parametric factor / function
s = corrective function
Statistically Valid Data

Requirements: Multiple observers, precision estimates, surface colors

- Witt
  Painted samples, hairline separation, 20%Y background, 22-24 observers

- Luo-Rigg
  Wool serge, hairline separation, 14.2%Y background, 20 observers
  Goal to combine 13 experiments each of about 20 observers

- RIT-Dupont
  Painted samples, hairline separation, 10.9% background, 50 observers
Visualization of Systematic Trends: Lightness $R^2=0.05$

- Luo-Rigg: Random
- Witt and RIT-Dupont: Consistent and different

Optimized Functions (not normalized)
Visualization of Systematic Trends: Chroma $R^2=0.70$

- Consistent trends for all data sets
- Main reason for improvement from:
  - Mc Donald, 1974
  - Mc Laren, 1976
  - JPC79, 1979
  - CMC, 1984
  - BFD, 1987
Visualization of Systematic Trends: Hue $R^2=0.45$

- Upward Trend
- Weaker Than Chroma Trend
Visualization of Systematic Trends: Hue Angle \( R^2=0.01 \)

Corrected for \( C^* \) position

- Random Dispersion
- No Consistent Trend
TC 1-29 Conclusions

- $S_L$ other than unity would fit parametric factors
- $S_L$ other than unity would not be universal across industries
- $S_C$ and $S_H$ functions should be linear due to data dispersion
- $S_H$ function should not have a hue angle dependency
CIE94 Equation

$$\Delta E_{94}^* = \left[ \left( \frac{\Delta L^*}{k_{LS_L}} \right)^2 + \left( \frac{\Delta C_{ab}^*}{k_{CS_C}} \right)^2 + \left( \frac{\Delta H_{ab}^*}{k_{HS_H}} \right)^2 \right]^{1/2}$$

$$S_L = 1$$

$$S_C = 1 + 0.045C_{ab}^*$$

$$S_H = 1 + 0.015C_{ab}^*$$

CIE 116-1995
CMC vs. CIE94
Lightness Tolerance

Who's right?
Optimizing Tolerances

22 observers making "pass/fail" decisions for 32 samples distributed about a standard
Optimized Ellipsoids for Four Observers, All Rejecting 18 Samples!

Who's right?
Optimized Ellipsoids for Three Observers

13, 19, and 25 samples rejected

Who's right?
Where Are We?

CMC
CIE94
Optimize visual/instrumental data
"Tomorrow is another day"
We Understand the Primary Limitation of CIELAB

Instrumental Color Tolerancing Can be Accomplished
Choose an Appropriate Equation

Be Conservative!

CIE94 unless you KNOW better
Only Adjust the Commercial Factor

One observer is never representative of a population.
Finally,

empower yourself through understanding

Thanks DCC for sponsoring this meeting.
And...

Support research that leads to improved equation development.

For example, join the:

Munsell Color Science Laboratory
Industrial Color Difference Consortium
Current Members:

3M
Bayer
Datacolor
Detroit Color Council
Dupont
Dystar
Gretag/Macbeth
Inter-Society Color Council
PPG
Society of Plastics Engineers
Xerox