Research and Education for Vision, Color and Image Sciences in Chiba University

Hirohisa Yaguchi
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History of Imaging Engineering in Chiba University

- 1920: Dept. of Graphic Arts, Tokyo Polytechnic College
- 1951: Dept. of Graphic Arts
  Dept. of Photographic Engineering, Chiba University
- 1964: Institute of Natural Color Engineering
- 1995: Center for Environmental Remote Sensing
- 1976: Dept. of Image Science
- 1989: Dept. of Information Science
- 1998: Dept. of Information and Image Sciences
- 2003: Center for Frontier Medical Engineering
- 2008: Dept. of Informatics and Imaging System
  Dept. of Image Sciences
  Dept. of Medical System Engineering
Education of Vision, Color and Imaging

- Faculty of Engineering (undergraduate students)
  - Visual Information Processing (Prof. Yaguchi)
  - Processing and Analysis of Color Image (Prof. Tominaga)
  - Digital Image Processing (Prof. Tominaga)
  - Image and Human Sensitivity (Prof. H. Kobayashi)
  - Human and Images (Prof. H. Kobayashi)
  - Image Recording Engineering (Prof. Kitamura)
  - Computer Graphics (Assoc. Prof. Tsumura)
  - Fourier Transform for Information and Image Sciences (Assoc. Prof. Horiuchi)
  - Medical Image Processing (Prof. Haneishi)
  - Remote Sensing Technology (Prof. Kuze)
  - Psychophysics (Assoc. Prof. Aoki)
  - Fundamentals of Image Science (Prof. Yaguchi et al.) for JPAC (Japan Program at Chiba for foreign students)
  - Development of Imaging Technology (Visiting Prof. Kuwayama)
  - Digital Imaging System (Visiting Prof. Kurosawa)
  - Design and Evaluation of Image Quality (Visiting Prof. Inui)
  - Image Electronics (Visiting Prof. Nakaya)
Education of Vision, Color and Imaging

- **Graduate School of Advanced Integration Sciences**
  - **Visual Science (Prof. Yaguchi)**
  - Color Reproduction (Prof. Yaguchi)
  - Image Kansei Engineering (Prof. Kobayashi)
  - Image Evaluation and Analysis (Assoc. Prof. Tsumura)
  - Electronic Imaging (Prof. Tominaga)
  - Medical Image Engineering (Prof. Haneishi)
  - Application of Remote Sensing Engineering (Prof. Kuze)
  - Pattern Recognition (Assoc. Prof. Horiuchi)
  - Image Analysis (Visiting Prof. Po-Chieh Hung)
  - Comparative Cognition (Prof. Jitsumori)
  - Form Perception (Prof. Kimura)
  - Cognitive Processing (Assoc. Prof. Ichikawa)
Vision Research Group in Chiba University

- Dept. of Information and Image Sciences, Faculty of Eng.
  - color vision, multispectral imaging, computer graphics, KANSEI engineering
- Dept. of Design, Faculty of Eng.
  - environmental humanomics, ergonomics
- Dept. of Architecture, Faculty of Eng.
  - lighting engineering, environmental design
- Dept. of Medical System Eng., Faculty of Eng.
  - brain imaging, fMRI, physiological optics, retina
- Div. of Behavioral Sciences, Faculty of Letter
  - cognitive and information sciences, psychology, comparative cognition
Current Research Projects in Yaguchi-Mizokami Labo

- Spatiotemporal aspects of color discrimination
- Color recognition and visual attention
- Color appearance in mesopic vision
- Color discrimination for color deficiencies and color universal design
- Analysis of image difference
- Measurement of contrast sensitivity functions
- Color rendering evaluation of solid state light sources
- Color appearance and discomfort glare of automotive headlamps
- Color appearance of human skin
- Perceived quality of wood image
- Natural environment and development of human color vision
- Color constancy and naturalness
Color Universal Design
How color deficiencies see color?

Simulation based on
Hans Brettel, Françoise Viénot, and John D. Mollon,
Computerized simulation of color appearance for dichromats,
Why color appearance for anomalous trichromat?

Main types of inherited color vision defects with approximate proportions of appearance in the population.

(R.Fletcher and J.Voke, Defective colour vision, fundamentals, diagnosis and management, Adam Hilger Ltd, 1985)
- Anomaloscope are used for classification of color deficiency types.
- In the anomaloscope, observers make color match between narrow-band yellow (590nm) and a mixture of narrow-band red (690nm) and green (545nm), so called Rayleigh match.
- Normal trichromat and anomalous trichromats make color matches with different R/G ratio with each other (Observer metamerism).
L-, M-, S-cone spectral sensitivities (CIE2006)
Log quantal absorbance of cone pigments as a function of wavenumber

- L-pigment
- M-pigment
- S-pigment

quantal absorbance (log units)

wavenumber (1/cm)
Spectral sensitivities of M’ (hybrid)-cones
(Deuteranomalous trichromat)
Spectral sensitivities of L’ (hybrid)-cones
(Protanomalous trichromat)
Derivation of the 2° cone fundamentals from the 10° cone fundamentals (CIE170-1)

Spectral shift in the wavenumber direction

Stiles & Burch
CMFs ⊘ 10 deg

10° cone fundamentals

\[ I_{10}(\lambda), \ m_{10}(\lambda), \ s_{10}(\lambda) \]

Lens pigment o.d.

Macular pigment o.d. ⊘ 10 deg

Cone photo pigment o.d. ⊘ 10 deg

Fitted CMFs ⊘ 2 deg

2° cone fundamentals

\[ I_{2}(\lambda), \ m_{2}(\lambda), \ s_{2}(\lambda) \]

Lens pigment o.d.

Macular pigment o.d. ⊘ 2 deg

Photopigment low density spectral absorbance

\[ A_{i\alpha(L\text{-pigment})}(\lambda) \]
\[ A_{i\alpha(M\text{-pigment})}(\lambda) \]
\[ A_{i\alpha(S\text{-pigment})}(\lambda) \]
Ocular density

- macular 2deg
- macular 10 deg
- lens

Ocular density (wavelength (nm))

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<table>
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<th>Wavelength (nm)</th>
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<tr>
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</tr>
<tr>
<td>550</td>
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<tr>
<td>650</td>
</tr>
<tr>
<td>750</td>
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The reconstructed cone fundamentals for the 2 deg observer

- The cone absorptance spectra in terms of quanta (Self-screening)
  \[ \alpha_{i,l}(\lambda) = 1 - 10^{-0.5A_{i,0}(L-pigment)(\lambda)} \]
  \[ \alpha_{i,m}(\lambda) = 1 - 10^{-0.5A_{i,0}(M-pigment)(\lambda)} \]
  \[ \alpha_{i,s}(\lambda) = 1 - 10^{-0.4A_{i,0}(S-pigment)(\lambda)} \]

- The cone fundamental spectral sensitivity in terms of quanta
  \[ L_q(\lambda) = \alpha_{i,l}(\lambda) \tau_{macula}(\lambda) \tau_{ocul}(\lambda) \]
  \[ M_q(\lambda) = \alpha_{i,m}(\lambda) \tau_{macula}(\lambda) \tau_{ocul}(\lambda) \]
  \[ S_q(\lambda) = \alpha_{i,s}(\lambda) \tau_{macula}(\lambda) \tau_{ocul}(\lambda) \]
Assumptions

- Spectral absorption of L-, M-cones are getting close.
  - Protanomalous: $\log A'_L(\nu) = \log A_L(\nu - \Delta \nu)$
  - Deuteranomalous: $\log A'_M(\nu) = \log A_M(\nu + \Delta \nu)$
- L-, M-, S-fundamentals specified with CIE170-1 (2006), Stockman and Sharp
- Transfer matrix of LMS to XYZ, CIE170-2 (2013)
  - $X = 1.94735469L - 1.41445123M + 0.36476327S$
  - $Y = 0.68990272L + 0.34832189M$
  - $Z = 1.93485343S$
- Second stage
  - Luminance $Y = k_L L + k_M M = 0.68990272L + 0.34832189M$
  - $r/g = \alpha_L L - \alpha_M M = 0.838812974L - 1.025975198M$
  - $y/b = \beta_y Y - \beta_S S = 0.516835014Y - S = 0.356565882L + 0.180024949M - S$
  - $r/g = y/b = 0$ for equal energy white ($X=Y=Z$)
- Color appearance would be reproduced from the second stage
  - $Y, r/g, y/b$ to XYZ then to RGB
Simulation flow

\[ \log A'_L(v) = \log A_L(v-\Delta v) \]
\[ \log A'_M(v) = \log A_M(v+\Delta v) \]
\[ \log A_S(v) \]

linear translation normalized with equal energy white

\[ \log A'_L(\nu) = \log A_L(\nu-\Delta \nu) \]
\[ \log A'_M(\nu) = \log A_M(\nu+\Delta \nu) \]
\[ \log A_S(\nu) \]

\[ \text{Lum}'(\lambda) = \int E(\lambda) \rho(\lambda) \text{Lum}'(\lambda) d\lambda \]
\[ r/g'(\lambda) = \int E(\lambda) \rho(\lambda) r/g'(\lambda) d\lambda \]
\[ y/b'(\lambda) = \int E(\lambda) \rho(\lambda) y/b'(\lambda) d\lambda \]

\( \rho(\lambda) \): spectral reflectance of the object
\( E(\lambda) \): spectral irradiance of the illuminant

Spectral shift
Spectral sensitivities at the second stage (Normal observer)

- Luminance \( Y = 0.69L + 0.35M \)
- \( r/g = 0.84L - 1.03M \)
- \( y/b = 0.36L + 0.18M - S \)
- \( r/g = y/b = 0 \) for equal energy white (\( X=Y=Z \))
Opponent color response

- Luminance: $Y' = k_I \left( \frac{L_{EW}}{L'_{EW}} \right) L' + k_m \left( \frac{M_{EW}}{M'_{EW}} \right) M'$
- $r/g' = \alpha_I \left( \frac{L_{EW}}{L'_{EW}} \right) L' - \alpha_m \left( \frac{M_{EW}}{M'_{EW}} \right) M'$
- $y/b' = \beta_y Y' - \beta_s S = k_I \left( \frac{L_{EW}}{L'_{EW}} \right) L' + k_m \left( \frac{M_{EW}}{M'_{EW}} \right) M' - S$
- $r/g' = y/b' = 0$ for the equal energy white ($X=Y=Z$)
Achromatic spectral sensitivities of anomalous trichromats

**Deutan**

- Normal
- Deuteranope
- "D(M-700)"
- "D(M-500)"
- "D(M-300)"
- "D(M-100)"

**Protan**

- Normal
- "P(L+100)"
- "P(L+300)"
- "P(L+500)"
- "P(L+700)"
- Protagane

*normalized with the equale energy white (same luminance)*
Red/green spectral sensitivities of anomalous trichromats

Deutan

Protan

*normalized with the equale energy white (r/g = 0)
Yellow/blue spectral sensitivities of anomalous trichromats

**Deutan**

- Normal
- Deuteranope
- D(L-700)
- D(L-500)
- D(L-300)
- D(L-100)

**Protan**

- Normal
- Protanope
- P(M+100)
- P(M+300)
- P(M+500)
- P(M+700)

*normalized with the equale energy white (r/g = 0)
Transfer matrix of XYZ to LMS (CIE170-2, 2013)

- \( X = 1.94735469L - 1.41445123M + 0.36476327S \)
- \( Y = 0.68990272L + 0.34832189M \)
- \( Z = 1.93485343S \)
- \( L = 0.21057582X + 0.855097643Y - 0.039698265Z \)
- \( M = -0.417076374X + 1.177261096Y + 0.078628251Z \)
- \( S = 0.516835014Z \)
Second stage to XYZ

- \( X = A + 1.654140017r/g - 0.36476327y/b \)
- \( Y = A \)
- \( Z = A - 1.93485343y/b \)
XYZ to sRGB

- $R = 3.2406X - 1.5372Y - 0.4986Z$
- $G = -0.9689X + 1.8758Y - 0.0415Z$
- $B = 0.0557X - 0.2040Y + 1.0570Z$
- $R_{8\text{-bit}} = R^{1/\gamma}$
- $G_{8\text{-bit}} = G^{1/\gamma}$
- $B_{8\text{-bit}} = B^{1/\gamma}$
Spectral reflectance of Macbeth Color Checker
Normal trichromat ($\gamma=1.8$)
Deuteranope ($\gamma=1.8$)
Deuteranomalous (M-700 cm⁻¹) (γ=1.8)
Deuteranomalous (M-500 cm^{-1}) (\gamma=1.8)
Deuteranomalous ($M-300\text{cm}^{-1}$) ($\gamma=1.8$)
Deuteranomalous (M-100 cm⁻¹) (γ=1.8)
Protopanomalous \((L+100\text{cm}^{-1})\) \((\gamma=1.8)\)
Protanomalous \((L+300\text{cm}^{-1})\) \((\gamma=1.8)\)
Protanomalous (L+500cm⁻¹) (γ=1.8)
Protanomalous \((L+700\text{cm}^{-1})\) \((\gamma=1.8)\)
Protanope ($\gamma=1.8$)
Color appearance for Protan

Normal

Protaanomalous (L+300)

Protanope

Protaomalous (L+700)
Multispectral images are needed for a real simulation of color appearance for anomalous trichromats.

Multispectral Image Database
Computer Vision Laboratory, Columbia University
Simulation of color appearance for anomalous trichromats

Deuteranomalous trichromats

M-100  M-300  M-500  M-700

Protanomalous trichromats

L+100  L+300  L+500  L+700

jelly beans
Simulation of color appearance for anomalous trichromats

Deuteranomalous trichromats

Protanomalous trichromats

Normal
L+100 L+300 L+500 L+700
M-100 M-300 M-500 M-700

Deuteranope
Protanope

beads
Simulation of color appearance for anomalous trichromats

Normal

Deuteranomalous trichromats

Protanomalous trichromats

Protanope

fake and real peppers
Color Vision and Application to Imaging Science

Physiology
- Retina
  - rods and cones
  - Horizontal cells
  - Bipolar cells
  - Amacrine cells
  - Ganglion cells

- LGN
  - Magno cellular
  - Parvo cellular

- Brain
  - V1
  - V2
  - V3
  - V4
  - ST
  - higher levels

Color Vision Model
- luminance channel
  - achromatic
- opponent color channels
  - red/green
  - yellow/blue

Color Vision and Application to Imaging Science

- Color Appearance
  - brightness, hue, chroma
  - color name, etc

- Colorimetric System
  - CIEXYZ (1931)
  - CIELAB (1976)
  - CIECAM (2002)

- Imaging System
  - Color reproduction for different image media
  - Gamut mapping
  - Categorical color reproduction
  - Total image quality

To investigate the mechanism of human vision
- To make color vision models
- To improve colorimetric systems

To apply the human color vision to imaging system
- Spectral sensitivity of image sensor
- Image difference formula
- Image compression
- Color space for communication
- White balance
Color and Image

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