A method for implementing CIECAM02 and CIECAM16 models

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1 Introduction to CIECAM Models

The CIECAM (CIE Color Appearance Model) models are frameworks developed by the CIE (International Commission on Illumination) to predict the appearance of colors under varying viewing conditions. The purpose of these models is to bridge the gap between the physical stimuli of light and how colors are perceived by humans. Unlike simpler color spaces such as CIE XYZ or CIELAB, which primarily quantify color based on linear or nonlinear transforms of physical data, CIECAM models consider the full context in which a color is viewed, including factors such as the brightness of the surrounding environment, the reference white, and the state of adaptation of the observer.

Two important versions of the model are:

- **CIECAM02**: A widely used color appearance model released in 2002. It was designed to improve upon previous models by offering better predictions of color appearance under diverse conditions.
- **CIECAM16**: The updated 2016 version which introduced refinements to the chromatic adaptation transform and enhanced some of the appearance correlates.

2 Purpose of CIECAM Models

The primary purpose of CIECAM models is to predict the perceptual attributes of color in different viewing conditions. These attributes include:

- **Lightness (J)**: The perceived brightness of an object in relation to a reference white.
- **Chroma (C)**: The colorfulness of a color relative to its brightness.
- **Hue (h)**: The attribute of color that allows it to be classified as red, green, blue, etc.

- **Saturation (s)**: The degree of colorfulness relative to the brightness of a similarly illuminated white.
- **Brightness (Q)**: The perceived intensity of light.
- **Colorfulness (M)**: The perceived magnitude of color independent of brightness.

These models help in predicting how colors will appear in various lighting conditions, which is especially important for industries such as display manufacturing, photography, and printing.

3 Description of the method

The method presented implements both CIECAM16 and CIECAM02 models. It takes in input values for the test sample's CIE XYZ coordinates, the reference white's CIE XYZ coordinates, the adapting luminance (L_A), the background luminance factor (Y_b), and additional parameters related to the viewing conditions such as the degree of adaptation, chromatic induction factors, and exponential non-linearity.

The code prompts the user to choose between the CIECAM16 and CIECAM02 models and then performs the respective calculations based on the chosen model. The results are the correlates of lightness, chroma, hue, saturation, brightness, and colorfulness.

4 Mathematical background of CIECAM Models

CIECAM models rely on several key transformations to convert CIE XYZ tristimulus values into perceptually uniform correlates. Below, we outline the main steps and equations involved in the CIECAM02 and CIECAM16 models.

4.1 Chromatic Adaptation

Chromatic adaptation accounts for the observer's visual adaptation to different illuminants. The chromatic adaptation transform in CIECAM02 is based on the following equation:

$$D = f\left(1 - \frac{1}{3.6}\exp\left(\frac{-L_A - 42}{92}\right)\right)$$

where:

- D is the degree of adaptation,
- f is the adaptation factor,
- L_A is the adapting luminance.

4.2 Sharpened RGB Transformation

To simplify chromatic adaptation, the XYZ values are converted into a sharpened RGB space using a transformation matrix. For example, in CIECAM02, this is done using:

$$\mathbf{RGB} = \mathbf{M}_{02} \times \mathbf{XYZ}$$

where $\mathbf{M}_{02}$ is the transformation matrix specific to CIECAM02, and $\mathbf{XYZ}$ represents the input tristimulus values.

4.3 Non-Linear Compression

Both CIECAM02 and CIECAM16 apply non-linear compression to the sharpened RGB values to account for the non-linearity in human perception. This is computed as:

$$\mathbf{RGB}_a = \left(\frac{400 \times (\mathbf{RGB}_c/100)^{0.42}}{27.13 + (\mathbf{RGB}_c/100)^{0.42}} \right) + 0.1$$

where $\mathbf{RGB}_a$ are the adapted post-compression RGB values.

4.4 Opponent Color Dimensions

In the opponent-color theory, color perception is divided into light-dark, red-green, and yellow-blue channels. The opponent color dimensions are computed as:

$$a = R_a - \frac{12}{11} G_a + \frac{1}{11} B_a$$

$$b = \frac{R_a + G_a - 2B_a}{9}$$

where R_a, G_a, and B_a are the adapted RGB values after non-linear compression.

4.5 Hue and Eccentricity Factor

The hue angle h is computed using the arctangent of the opponent color dimensions:

$$h = \text{atan2}(b, a)$$

To improve the prediction of chroma, the eccentricity factor is introduced:

$$e_t = \frac{\cos(h + 2^\circ) + 3.8}{4}$$

4.6 Lightness, Brightness, Chroma, and Saturation

The correlate of lightness J is computed as:

$$J = 100 \left(\frac{A}{A_w} \right)^{cz}$$

where A is the achromatic response, and A_w is the achromatic response for the reference white. The brightness Q is computed as:

$$Q = \frac{4}{c}\sqrt{\frac{J}{100}} \times (A_w + 4) \times F_L^{0.25}$$

Chroma C and saturation s are given by:

$$C = t^{0.9}\sqrt{\frac{J}{100}}(1.64 - 0.29^n)^{0.73}$$

$$s = 100\sqrt{\frac{M}{Q}}$$

5 Conclusion

CIECAM16 builds upon the foundations of CIECAM02 but introduces several refinements in key aspects of the model. One significant technical improvement is in the chromatic adaptation transform. In CIECAM16, the chromatic adaptation matrix is slightly modified to improve the accuracy of color appearance predictions, particularly for bright and highly saturated colors. Another difference is the introduction of a refined exponential non-linearity in the post-adaptation response compression. This update helps CIECAM16 to better model the perceptual differences in lightness and chroma, especially under diverse lighting conditions. While the core structure of both models is similar—including steps like converting XYZ tristimulus values to sharpened RGB, applying non-linear compression, and computing opponent color dimensions—CIECAM16 tends to provide a more perceptually uniform and accurate prediction of color appearance, particularly in complex viewing environments.

6 References

1. Fairchild, M. D. (2013). Color appearance models. John Wiley & Sons.

2. CIE 248:2022, Division 1 Division 8, ISBN: 978-3-902842-94-7, The CIE 2016 Color Appearance Model for Color Management Systems: CIECAM16, Vienna: CIE(2022).