

Usage Guidelines for CIECAM97s

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Abstract

Color appearance models provide a powerful tool for achieving a viewing condition independent color representation. However, current color appearance models such as CIECAM97s[1,2] and CAM97s2[3] are more complex than previous CIE device independent color spaces[4], such as CIELAB and CIELUV. Therefore it is important to understand how to correctly measure and set the input parameters. This paper provides details about how to set the luminance of the adapting field, the surround, the luminance of the background, and the white point. There is also discussion of the format of the input perceptual attributes, the output perceptual attributes and example parameter settings for a range of viewing conditions.

Introduction

The CIECAM97s color appearance model can be used to convert from tristimulus values to perceptual attributes. The inverse model can be used to convert from perceptual attributes back to tristimulus values. The input and output viewing conditions are used during the forward and inverse calculations to account for differences in viewing conditions. Therefore, CIECAM97s can be used to achieve device and viewing condition independent color.[5] This enables a range of additional algorithms and processing and is only part of a larger framework for managing color. A general flowchart for CIECAM97s is shown in Figure 1. In this figure, input tristimulus values are converted to perceptual attributes and then transformed back to tristimulus values as the data flows from the top to the bottom of the flowchart. CIECAM97s does not define other operations such as white point estimation[6] or processing out of gamut colors.[7] However there are a range of color and image processing algorithms that can benefit by operating on the perceptual attributes computed by CIECAM97s. For example, uniform color spaces and perceptual attributes have been used for dynamic range adjustment,[8] color quantization,[9] compression and decompression,[10] preference adjustments[11] and other operations.

The input and output viewing conditions can be set or determined in a number of ways. First, the viewing conditions can be estimated by direct measurement. This approach is useful for hardcopy or softcopy viewing. Second, correlation techniques or psychophysics can be used to determine the viewing conditions. These approaches are useful for scene analysis or complex viewing environments. Lastly the viewing condition tags could be used to select from a set of standard viewing conditions.

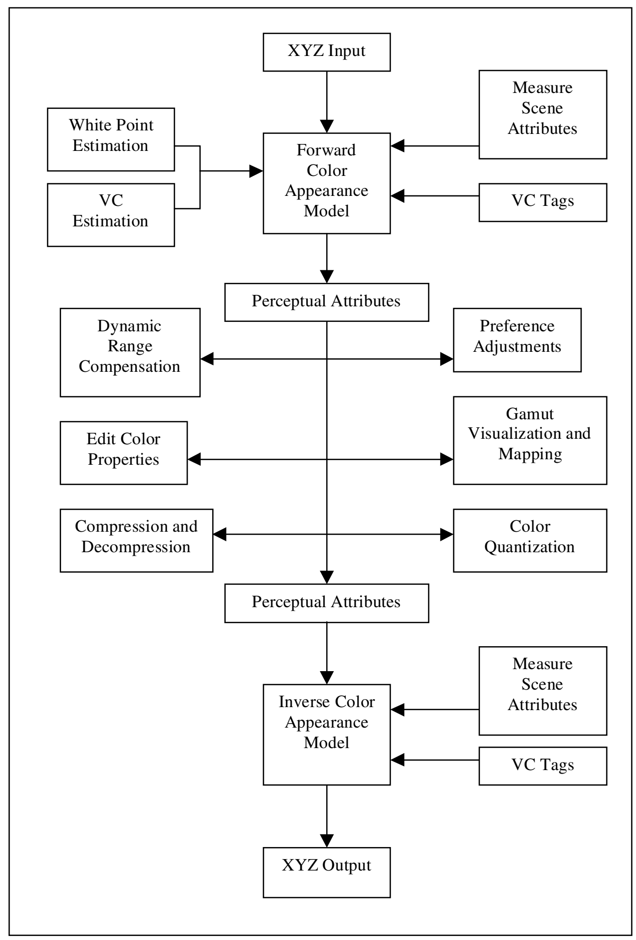

Figure 1. A general flowchart for CIECAM97s.

The viewing conditions for CIECAM97s have been previously defined[12] but it is worth reviewing the specific pieces. First, is the stimulus color or the 2-degree subtense in the center of the visual field. The 10 to 12 degrees around the stimulus is the background. The remainder of the visual field outside of the background is the adapting field. These concepts are shown in Figure 2. Useful rules[13] for these items are that the thumb has a roughly 2-degree subtense at arms length while the closed fist subtends about 10 degrees. The distance for the end of the pinky to the end of the thumb when the figures are stretched is about 20 degrees. These general rules are based on the fact that the size of hands and fingers is generally correlated to arm length.

Figure 2. Simplified viewing environment. The stimulus color is the central circle while the background is the outer circle. The adapting field is the region outside of the outer circle.

Luminance of Adapting Field

The luminance of the adapting field or La, is the luminance of the visual field outside of the background. The units for La are in cd/m2 and can be measured using a photometer. In the first case, a white reference such as pressed halon can be measured using an appropriate geometry. In the second case, a cosine detector or an integrating mechanism can be used to measure illuminance or lux. Given illuminance, luminance can be computed:

$$L = \frac{E \cdot R}{\pi}. \quad (1)$$

where E is the illuminance in lux R is the reflectance and L is the luminance. For a perfectly reflecting diffuser, the value of R can be set to 1. As a result, equation one can be simplified to luminance equals illuminance divided by π.[14] However, for La this luminance is divided by 5 in order to incorporate a gray world assumption. This can be expressed:

$$L_a = \frac{L}{5}. \quad (2)$$

For example the sRGB standard[15] has an ambient illumination level of 64 lux or an La value of 4. Annex D in the sRGB standard provides a typical office ambient illumination of 350 lux or an La value of 22. The values of La are listed to the nearest one, given that the CIECAM97s model is not sensitive enough to La to justify additional precision.[16]

Surround

There are four defined surrounds for CIECAM97s: average, dim, dark and cut-sheet. The surround is categorical and is defined based on the relationship between the relative luminance of the surround and the luminance of the scene or image white.[12] The surround can also be defined by comparing the surround luminance to the average luminance of the viewing field.[2] The luminance of the surround can be computed from the ambient illumination.

A dark surround has a relative surround luminance that is 0% of the luminance of the scene white. A dim surround has a relative surround luminance between 0% and 20% of the luminance of the scene white. An average surround has a relative surround luminance of greater than 20% of the luminance of the scene white. The cut sheet surround is a specific surround for viewing of cut sheet transparencies. The four surrounds and example applications[2] are listed in Table 1.

Table 1. Listing of three of the CIECAM97s surrounds.

Surround	**Surround Relative Luminances Compared to Scene White[12]**	**Application[2]**
Dark	0%	Viewing film projected in a dark room
Dim	0% to 20%	Viewing television
Average	> 20%	Viewing surface colors
Cut-Sheet	-	Viewing cut-sheet film on light boxes

An example is useful to illustrate how surround is determined. For the sRGB specification, the ambient illumination level is 64 lux and the monitor white is 80 cd/m^2. Using equation 1 the surround luminance can be computed to be 20.4 cd/m^2. This value is greater than 16 cd/m^2 or 20% of the monitor white. Therefore the sRGB surround would be average. Using an ambient illumination level of 350 lux results in a surround luminance of 111 cd/m^2 and is also an average surround.

Background Luminance

The background is the region immediately surrounding the stimulus and for images is the neighboring portion of the image. Generally, this value is set to a value of 20. This implicitly assumes a gray world assumption. For spot colors or other simple color stimuli on a uniform background it may be possible to directly measure the luminance of the background relative to the luminance of a reference white.

A value of 18 has been used in some cases[2] but this is just a variation on the gray world assumption and results when an L* of 50 is converted to luminance. It is also a small enough difference that it will have a minimal impact on the CIECAM97s calculations. However for consistency it may be useful to have a default value for Yb. The sRGB specification defines a viewing condition with the surround having a 20% reflectance of the reference ambient. Assuming a spectrally flat reflectance then the corresponding value of Yb is 20.

White Point

The white point is an important input parameter that is used in both the chromatic adaptation transform and during the calculation of the perceptual attributes. Recently, the terms adopted and adapted white points have come into use. At this point in time, there are no official CIE definitions for these terms although there are working definitions.[17]

Adopted White Point – The computational white point or the white point used during the CIECAM97s calculations.

Adapted White Point – The observer white point or the internal human visual system white point for a given set of viewing conditions.

In general, the best results will be achieved when the adopted white point is the adapted white point. However, in the absence of data it may be necessary to assume a default adopted white point, even though that may differ from the actual adapted white point.

The white point has been shown to be an important input parameter for CIECAM97s.[16] For monitors in a dark surround, the white point can be measured or determined using psychophysics. For a printed image, the white point can be measured using the media white under the appropriate viewing conditions. Mixed mode illumination, such as a monitor viewed under an ambient illumination with a different white point[18] or a scene with two different sources of ambient illumination[17] are more complex. In the first case, the background is a critical factor that determines the adapted white point. In the second case it is less clear and more investigation is necessary to determine the optimal adapted white point.

Input Tristimulus Values

Unlike CIELAB, the range of the input tristimulus data impacts the resulting CIECAM97s calculations. Specifically, absolute and relative colorimetry are not the same.[19] For instance, the data shown in Table 2 demonstrates how differences between the absolute and relative input tristimulus data have no effect on the resulting L* value. In comparison, the CIECAM97s J value is slightly different depending on whether the input data has been normalized to the range 0 to 100 or not. While the differences in J are small in this case, they can be magnified if the range of the absolute tristimulus data becomes much larger or smaller.

Table 2. Absolute versus relative tristimulus data as input to CIELAB L* and CIECAM97s J calculations.

	Relative	**Absolute**
X	19.01	15.21
Y	20.00	16.00
Z	21.78	17.42
Xw	95.05	76.04
Yw	100.00	80.00
Zw	108.88	87.10
La	318.31	318.31
Yb	20	20
Surround	Average	Average
L*	51.84	51.84
J	42.44	41.28

The results shown in Table 2 indicate that it is important to establish a convention for the input tristimulus data. Given that many imaging pipelines incorporate at least one normalization step during processing, it is important that there is consistency in the overall processing. Therefore it is recommended that all input tristimulus data be normalized before computing CIECAM97s perceptual attributes.

Output Attributes

CIECAM97s can be used to compute lightness, brightness, chroma, saturation, colorfulness and hue. These attributes can be abbreviated to J, Q, C, s, M, and h. It is important to note that rectangular coordinates must be computed for each combination of attributes. The following equations and notations may be useful for differentiating the three rectangular coordinate systems that can be derived from the CIECAM97s attributes:

$$a_C = C \cdot \cos(h) \ \ and \tag{3}$$

$$b_C = C \cdot \sin(h)\,, \tag{4}$$

where the C is the chroma and h is the hue angle.

$$a_s = s \cdot \cos(h) \ and \tag{5}$$

$$b_s = s \cdot \sin(h)\,, \tag{6}$$

where the s is the saturation and h is the hue angle.

$$a_M = M \cdot \cos(h) \ and \tag{7}$$

$$b_M = M \cdot \sin(h)\,. \tag{8}$$

where M is the colorfulness and h is the hue angle. While C, s and M subscripts are not defined in any of the CIE or other documents, they should be used in order to avoid confusion with one another and with the preliminary a and b opponent axes. Note that JCh can be used much as LCh are in CIELAB, such as for gamut mapping. Jsh can also be useful for gamut mapping. Lastly QMh could be used for analysis of gamut volume[20] or for situations in which matching brightness and colorfulness is more appropriate than lightness and chroma matching. It is important to note that the output attributes should not be mixed and matched arbitrarily.[12]

Example Viewing Conditions

A range of viewing condition parameters is shown listed in Table 3. These viewing conditions are a collection of viewing conditions that the author has found useful for various purposes. This table is provided to illustrate how the CIECAM97s viewing condition parameters can be set based on the viewing conditions

The third column of Table 3 lists the ambient illumination level or levels. The fourth column of this table is the La value that corresponds to the given illumination level. The values of La were computed using equations 1 and 2. The white point and background are shown in columns five and six, respectively. The specification of the background properties is consistent in that it should be achromatic but the exact value of Yb ranges from 18 to 36.6. In all cases, the surround is average. Lastly, there is a column for miscellaneous comments.

Conclusion

The luminance of the adapting field or L_a can be computed from measurements of the ambient illumination. Illuminance and luminance can be converted to L_a by dividing by 5π and 5, respectively. The surround is categorical and can be determined by comparing the ratio of the scene or stimulus white with the level of ambient illumination. This ratio can be used to differentiate the dark, dim and average surrounds. For viewing environments with a single white point, the value can be measured directly while multiple illuminant white points require some approximation. The effect of using absolute versus relative tristimulus values is also considered. Unlike CIELAB, CIECAM97s will not map all white points to the same value and will compute slightly different values based on the absolute values of the stimulus luminance. Lastly, a table of example settings is presented for a selection of common and standard viewing conditions.

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Biography

Nathan received his Bachelors degree in Color Science from the Philadelphia University and his Masters degree in Color Science from the Munsell Color Science Laboratory at the Rochester Institute of Technology. He has worked at the RIT Research Corporation and the Barcelona division of Hewlett-Packard. Nathan currently works in the Color Imaging and Printing Technologies Department at Hewlett-Packard Laboratories. He has worked on a range of topics in the area of digital color imaging and is currently a member of the CIE technical committee TC 8-01 working on a color appearance model for color management systems.

Table 3. CIECAM97s settings for various average surround example viewing conditions.

	Application	Ambient Illuminance	La	White Point	Background	Comments
ASTM D 1729-89	Visual evaluation of color differences[21]	2150, 810-1880 and 510 lux	137, 86, 32	Multiple	N6 to N7, Yb = 36.6	Illuminance as a function of sample lightness
Author's Cubicle	Daily working environment for the author	511 lux Range is 270 to 730 lux	33	0.397, 0.390 ambient with natural daylight and fluorescent	Complex, assume that Yb = 20	Averages based on 31 measure-ments
CIE 116-1995	ΔE94 color difference metric[22]	1000 lux	64	D65	L*=50, Yb = 18	< 4 degree subtense
ISO-3664 P1	Critical print evaluation[23]	2000 lux ±500 lux	127	D50	<60%, assume recommended Yb = 20	75% uniformity over 1 m^2
ISO-3664 P2	Practical print evaluation[23]	500 lux ±125 lux	32	D50	<60%, assume recommended Yb = 20	White point ± 0.005
ISO 9241	Ergonomics for computer products[24]	500 lux Range is 200 to 700 lux	32	Natural	-	400 mm -100 and + 200 mm distance
Munsell Book of Color	Color order system[25]	220 lux	14	C	N5, Yb = 19.77	Historical conditions, currently reference ASTM 1729
OSA Uniform Color Scales	Color order system[26]	≤ 500 lux	32	D65	30% Reflectance, Yb = 30	Based on the 10 degree observer
sRGB	Default color space for the Internet[15]	64 lux ambient 80 cd/m2 CRT	4	D50 ambient and D65 CRT	20% Reflectance, Yb = 20	Use D65 as white point
sRGB: Annex D	Default color space for the Internet[15]	350 lux ambient	22	D50 ambient and D65 CRT	20% Reflectance, Yb = 20	Ongoing research on white point