A Robust Hue Descriptor

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Abstract

A hue descriptor based on Logvinenko's illuminant-invariant object colour atlas [1] is tested in terms of how well it maps hues to the hue names found in Moroney's Colour Thesaurus [2][3] and how well it maps hues of Munsell papers to their corresponding Munsell hue designator. Called the KSM hue descriptor, it correlates hue with the central wavelength of a Gaussian-shaped reflectance function. An important feature of this representation is that the set of hue descriptors inherits the illuminate invariant property of Logvinenko's object colour atlas. Despite the illuminant invariance of the atlas and the hue descriptors, metamer mismatching means that colour stimulus shift [4] can occur, which will inevitably lead to some hue shifts. However, tests show that KSM hue is robust in the sense that it is much more stable under a change of illuminant than CIELAB hue.

Introduction

Hue is a very important property of colour. Conventionally, hue is described in terms of the angular component of the polar representation of a colour in an opponent colour space such as CIELAB in which two of the axes are perceptually orthogonal to lightness. Although these colour spaces may work well for a fixed illuminant, they can lead to unstable results when the illuminant is changed. The source of this instability is that CIELAB and related spaces account for the illumination via von Kries scaling, but von Kries scaling can be subject to very large errors [5]. Logvinenko introduced an illumination-invariant colour atlas to represent the colour of objects [4] that addresses this problem. He defines an object-colour atlas in terms of a special set of non-metameric, rectangular spectral reflectance functions. He showed that the central wavelength parameter of the rectangular reflectance provided a reasonably good perceptual correlate to hue. Subsequently, Mirzaei et al. [6] showed that the central wavelength parameter of the wraparound Gaussian reflectances of Logvinenko's Gaussian parameterization of the colour atlas provides an even better correlate to hue and is simultaneously more robust to metamerism-induced colour stimulus shift when tested on the set of 1600 Munsell papers.

This paper investigates the Gaussian-based hue descriptor relative to CIELAB's hue in terms of (i) how well it describes the hues of Munsell papers and the hues from the Color Thesaurus derived from Moroney's on-line colour naming experiment, and (ii) how stable the respective hue descriptors are under a change in the illuminant.

Hue Correlate in Logvinenko's Object Colour Atlas

Logvinenko's Gaussian parameterization of the rectangular colour atlas involves reflectances defined in terms of a 3-parameter wraparound Gaussian function $g(\lambda;k,\sigma,\mu)$ defined as follows:

If $\mu \leq (\lambda_{\max} + \mu_{\min})/2$:

1. For $\lambda_{\min} \leq \lambda \leq \mu + \Lambda/2$: $g(\lambda;k,\theta,\mu) = k\exp[-\theta(\lambda-\mu)^2]$

2. For $\mu + \Lambda/2 \leq \lambda \leq \lambda_{\max}$: $g(\lambda;k,\theta,\mu) = k\exp[-\theta(\lambda-\mu-\Lambda)^2]$

On the other hand, when $\mu \geq (\lambda_{\max} + \mu_{\min})/2$:

1. For $\lambda_{\min} \leq \lambda \leq \mu - \Lambda/2$: $g(\lambda;k,\theta,\mu) = k\exp[-\theta(\lambda-\mu+\Lambda)^2]$

2. For $\mu - \Lambda/2 \leq \lambda \leq \lambda_{\max}$: $g(\lambda;k,\theta,\mu) = k\exp[-\theta(\lambda-\mu)^2]$

where $\lambda_{\max}$ *and* $\lambda_{\min}$ are the ends of the visible spectrum, $\Lambda = \lambda_{\max} - \lambda_{\min}$ and $\theta = 1/\sigma^2$. For $0 \leq k \leq 1$, $\lambda_{\min} \leq \mu \leq \lambda_{\max}$ and positive θ, we have a Gaussian reflectance (i.e., it is everywhere between 0 and 1) spectrum. We will refer to the triple $k\sigma\mu$ as the KSM coordinates, where σ stands for standard deviation, μ for peak wavelength, and k for scaling. Mirzaei et al. [6] show that μ (central wavelength) correlates well with the Munsell hue designator. In what follows, we will refer to μ as *KSM hue* and compare it to CIELAB hue. The experiments below show two important properties of KSM hue. First, it correlates well with the hue names Moroney found [2][3] in his on-line colour naming experiment. Second, KSM hue is much more stable under a change of illuminant than CIELAB hue.

KSM Hue versus and CIELAB hue under D65

In order to determine whether KSM hue provides a good perceptual hue correlate, we test with respect to the Moroney colour names and the Munsell hue designators.

KSM Hue to Thesaurus Hue Names

A related concept to hue categorization is colour naming. Moroney's colour thesaurus summarizes the result of a very large on-line colour naming experiment [2][3]. In his experiments people are asked to provide unconstrained colour names for colours displayed against a uniform grey background viewed on an uncalibrated computer display. How well do KSM hue and CIELAB hue predict the colour names found in the thesaurus? Many of the hue names in the thesaurus are not standard hue names (e.g., 'crimson,' 'sunburst,' 'seafoam'). However, many others like 'fire red' and 'sea green' include a standard hue name as a component of the name. To limit the set of hues to 'standard' ones, the tests described below are based on all the colour names from the colour thesaurus that included the 11 colour names red, green, yellow, blue, brown, purple, pink, and orange of Berlin and Kay [7], excluding black, gray, and white. The thesaurus is searched for all colour names that include one of these 11 as a component; however, those that include more than one of the 11 names as components are excluded. For example, names such as ‘delft blue’ and ‘sage green’ are include under the categories blue and green, but ‘blue green’ is excluded since it is not clear whether it describes a blue or a green. The result is 8 sets of colour names of which there are 22 red, 99 green, 18 yellow, 79 blue, 14 brown, 21 purple, 28 pink, and 14 orange.

Each entry in the thesaurus has an associated sRGB colour descriptor. This sRGB value is converted to CIELAB and KSM [8][9] coordinates under the assumption that the display settings and viewing environment are intended to be D65. It should be noted that Logvinenko’s colour object colour atlas describes the colours of objects (surfaces) not lights. Converting sRGB to KSM implies that the sRGB values are recorded from a surface, when in fact in Moroney’s experiment they were not, but rather from the light emanating from an emissive display. This might mean that KSM hue will not model displayed colours as well as object colours, but the results below show that it models display colours well in any case.

Figure 1 plots the 8 colour name sets in terms of hue and saturation. CIELAB includes a definition of saturation as well as hue. For KSM the standard deviation of the Gaussian defined by parameter σ is used as the correlate of saturation, following on the use of spectral bandwidth δ for saturation in Logvinenko’s rectangular atlas. How well σ correlates with saturation will be investigated elsewhere. In the present context, it simply spreads out the Figure 1 plots nicely. All the analysis here is strictly in terms of KSM hue.

Since CIELAB was developed as a perceptually uniform colour space based on psychophysical experiments, one might expect CIELAB hue to correlate better with the colour name categories extracted from the colour thesaurus than KSM hue. However, as can be seen from Figure 1, KSM hue appears to correlate with the hue names as well or better than CIELAB hue in terms of compactness of the hue range along the hue axis, and distinctiveness of the hues from one another. To compare the two hue descriptors quantitatively, we test their effectiveness when used for automatic hue classification. For this, the KSM and CIELAB hues are input as feature vectors to a classifier based on linear discriminant analysis (Matlab’s Classify function). The misclassification rate for the classifier based on KSM hue is 21%, whereas, for the classifier based on CIELAB hue it is 39%. In other words, KSM hue successfully distinguishes 79% of the samples compared to CIELAB hue at 61%.

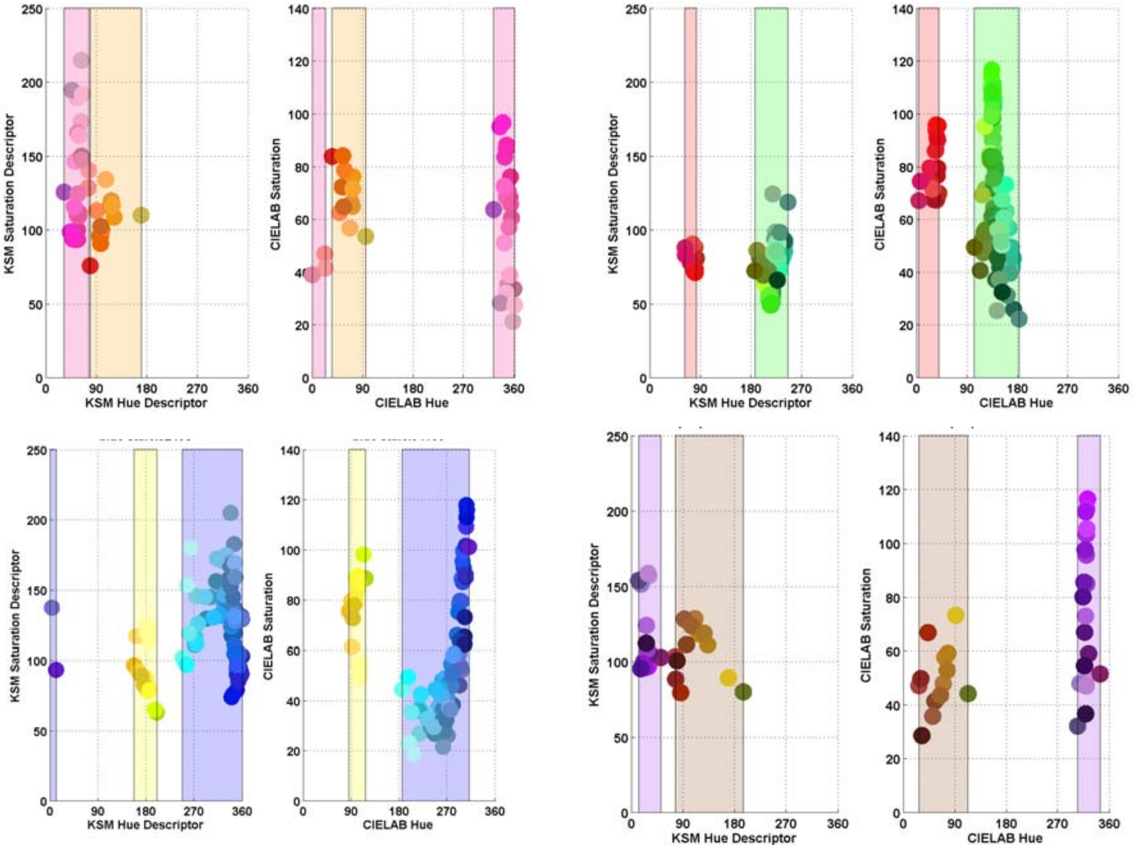

__Figure 1.__ The colours from the 8 sets of names from the colour thesaurus plotted as points (μ, σ) in the left columns and (CIELAB saturation, CIELAB hue) in the right columns of each panel. Each panel illustrates two hue names, which are pink and orange, red and green, yellow and blue, purple and brown. For each colour name, the narrowest rectangle enclosing the points is included to indicate the limits of the hue descriptors for the corresponding colour name. The colour of each point represents (approximately) the sRGB colour of the corresponding thesaurus entry.

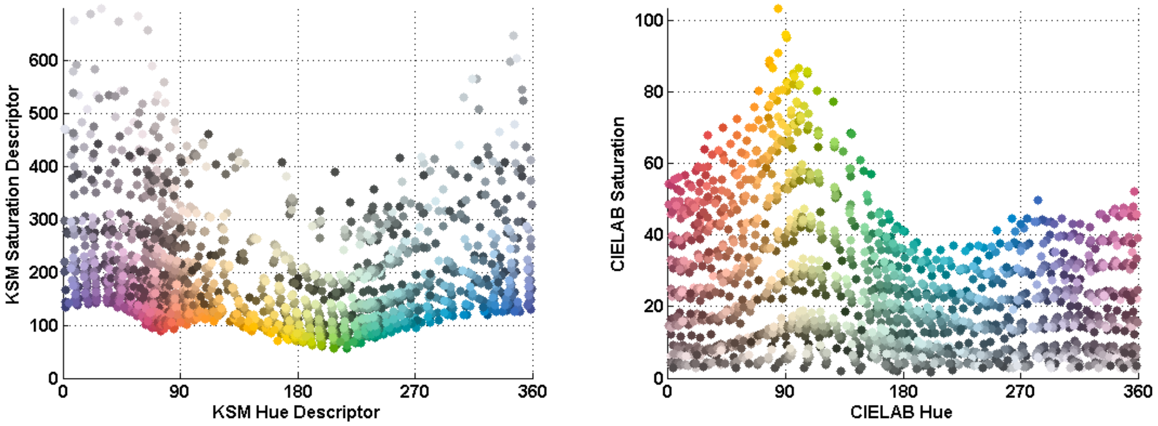

Figure 2. *KSM hue and CIELAB hue of Munsell papers having Munsell hue designators R, YR, Y, GY, G, BG, B, PB, P, and RP. The points are plotted as (hue, saturation) points.*

Hue Correlate of Munsell Chips

As a further comparison of KSM and CIELAB hue correlates, we consider the set of 1600 papers of the Munsell glossy set. This follows a similar analysis by Logvinenko [4] of his rectangular hue correlate. We synthesized the XYZ tristimulus values of all 1600 papers based on the Joensuu Color Group spectral measurements [10] under D65 using the CIE 1931 $\bar{x}\bar{y}\bar{z}$ (the 2 degree observer) colour matching functions and then computed the corresponding KSM and CIELAB hues. As shown in Figure 2, KSM hue and CIELAB hue each appear to correlate to about the same degree with the Munsell hue designator for papers of a given hue but varying chroma and value. This is indicated by the fact that the colours of the same hue align vertically. To be more quantitative, again we consider the hue classification task for 10 different hues and input the KSM and CIELAB hues as feature vectors to the classifier and obtain very similar misclassification rates of 24% using KSM and 22% using CIELAB hue.

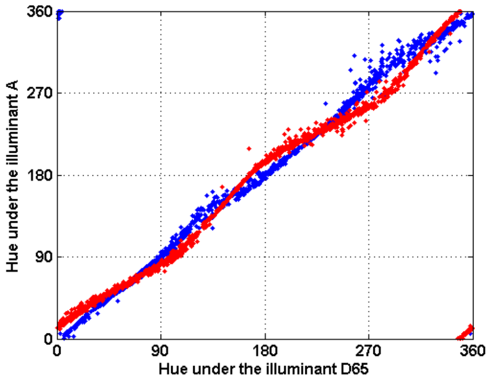

Figure 3. *The KSM hue (blue dots) and CIELAB hue (red dots) of Munsell papers in degrees under illuminants D65 and A. A hue descriptor that is completely invariant to the illumination would lead to points lying strictly on the diagonal.*

Table 1: The KSM and CIELAB hue shift for the Munsell papers in degrees evaluated with circular statistics for illuminants D65 and A.

	Median	Mean
KSM hue shift	2.17	3.73
CIELAB Hue shift	8.62	8.57

As a further test of the stability of KSM and CIELAB hue, we use all non-identical pairings of the different illuminants used by Logvinenko an Tokunaga [11] in their asymmetric colour matching experiments, excluding red (R2) since it is very similar to R1. The illuminant spectra are plotted in Figure 4. With the exception of the neutral illuminant, these lights are quite distinctly coloured. As in the test described above using D65 and A, we first calculate the XYZ tristimulus values of Munsell chips under each of the illuminants and then compute the corresponding KSM and CIELAB hues.

Based on circular statistics, the mean and median differences of the KSM hues and CIELAB hues for the different illuminant pairs are tabulated in the Table 2. Clearly, KSM hue is significantly more stable than CIELAB hue.

As a final note, we also carried out a comparison with CIECAM02 [12]. When calculating the CIECAM02 appearance attributes, we adopted the parameters suggested for a dim surround. However, changing the parameters did not substantially change the average CIECAM02 results compared to those of CIELAB. As an example, the misclassification rate for CIECAM02 versus CIELAB hue for the Moroney hue names was 35% versus 39% (KSM 21%) and for the Munsell hue names 22% versus 22% (KSM 24%). In addition, in terms of the illuminant invariance, the CIECAM02 hue is no more stable than CIELAB hue.

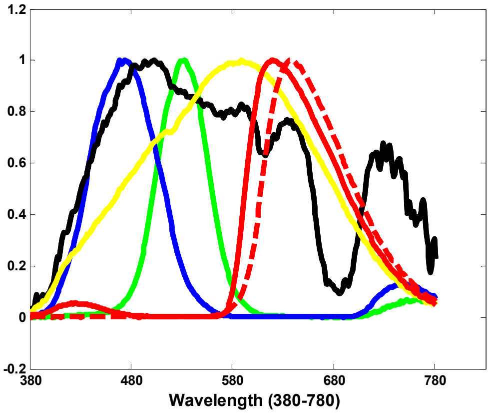

Figure 4. *Spectra of the green (G), blue (B), neutral "white" (N), yellow (Y), first red (R1) and second red (R2) illuminants used in Logvinenko and Tokunaga's experiments [11]. The curve colours indicate the associated spectrum along with black for N and dashed red for R2.*

Table 2. The Median and Mean shift in degrees in KSM hue versus CIELAB hue for the 1600 Munsell papers for each illuminant pair.

Illuminants		Median Difference		Mean Difference	
1	2	KSM Hue	CIELAB Hue	KSM Hue	CIELAB Hue
G	B	8.42	32.02	10.99	33.91
G	N	5.79	17.16	6.24	15.77
G	Y	5.62	15.98	6.71	16.53
G	R1	12.84	43.11	15.19	41.54
B	N	3.74	21.64	8.07	26.06
B	Y	4.52	25.65	9.66	29.17
B	R1	10.00	48.05	14.82	47.12
N	Y	0.85	3.67	1.70	3.67
N	R1	7.44	28.19	10.10	30.20
Y	R1	7.22	26.71	9.32	27.53
Mean		**6.64**	**26.22**	**9.28**	**27.15**

Conclusion

The peak wavelength parameter of the Gaussian parameterization of Logvinenko's [1] KSM object colour atlas has been shown to provide a good perceptual correlate of the hue of object colour that is robust relative to the spectrum of the illuminant. Called KSM hue, it not only is better at categorizing the names from Moroney's colour thesaurus than CIELAB and CIECAM02 hue, KSM hue is also substantially less affected by the illuminant. KSM hue leverages the illuminant invariance of the KSM colour atlas. The KSM hue changes that do occur with a change in illumination are entirely a result of the unavoidable phenomenon of colour stimulus shift induced by metamerism.

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