Cone-signal ratio dependence on natural and artificial illuminants

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ABSTRACT

We have studied the dependency of cone-signal ratios obtained for daylight and equienergetic illuminants, with the color temperature of daylight, also for the signals generated by the second-stage mechanisms of color vision. The linearity of the cone-ratio were also tested for artificial illuminants (F2, F7, F11 and A). The results obtained for such illuminants are similar to those obtained for daylight. The mathematical expressions obtained for the daylight and the value of the ratios for artificial illuminants were applied to the synthesis of color images under different conditions. The results show a good agreement in terms of color-difference evaluation between the original and predicted images of a natural or artificial scene.

1. INTRODUCTION

Different authors[1-4] have shown a roughly linear relationship between the excitation values of cones (L, M, S) found for a set of objects under a natural illuminant (daylight) and their respective values found for other daylight with a different colour temperature. That is, the L-value ratio remains constant for the different objects when these values are calculated for two natural illuminants. This constancy also occurs when the equienergetic and planckian illuminants are considered[2, 3]. When the values generated by the second-stage mechanisms (red-green, yellow-blue, and achromatic) are obtained, new linear relationships are found[3-5] both theoretically as well as experimentally. However, in the above-mentioned works, it has not been studied how the coefficients of these linear relationships vary with the changes in illumination. This is the prime objective of our work: to formulate equations that enable us to link the ratio coefficients of the cone and second-stage signals with the colour temperature of the natural illuminants. To achieve this purpose we have adjusted a linear relationship for each cone and second-stage mechanisms, for a broad set of objects, with daylight and with an equal-energy illuminant. This was repeated for a broad set of daylight of different colour temperatures. In addition, we broadened our study to the artificial illuminants A, F2, F7 and F11. In the final stage of our study, we analysed the possible application of our results to the synthesis of colour images.

2. METHOD AND RESULTS

For this study, we used a set of 71 natural objects[6] for which we knew their spectral reflectances, 240 artificial objects[7], and 22 phases of daylight[8] with colour temperatures of between 30.8 and 266.1 mireds, corresponding to cloudy and clear skies, respectively, in the middle hours of the day and at twilight. On establishing the values L, M, S, (L+M+S), L/(L+M) and S/(L+M) for the sets of objects and a given daylight, we represented, for each parameter, its values on ordinates and on abscissas those corresponding to the equal-energy illuminant, calculating the values the slope, the intercept value and the correlation coefficient of the linear regression.

Analyzing natural objects, the correlation coefficients for the L, M, S and S/(L+M) values were consistently greater than 0.99, also for the L/(L+M) and (L+M+S) values with the exception for daylights with colour temperatures less than 70 mired (twilights), where the correlation coefficients worsens a bit. For artificial objects the results are quite similar than for natural objects with the exception for S/(L+M). In this case the correlation coefficients are less than 0.99 for daylight colour temperatures bellow than 120 mireds and above 235 mireds, that it to say the linear regression it can be considered only satisfactory for the central hours of the day. The ordinates at the origin of the adjusted straight lines (intercept values) proved very close to zero in all the cases. In figure 1 we show some examples of the adjustments.

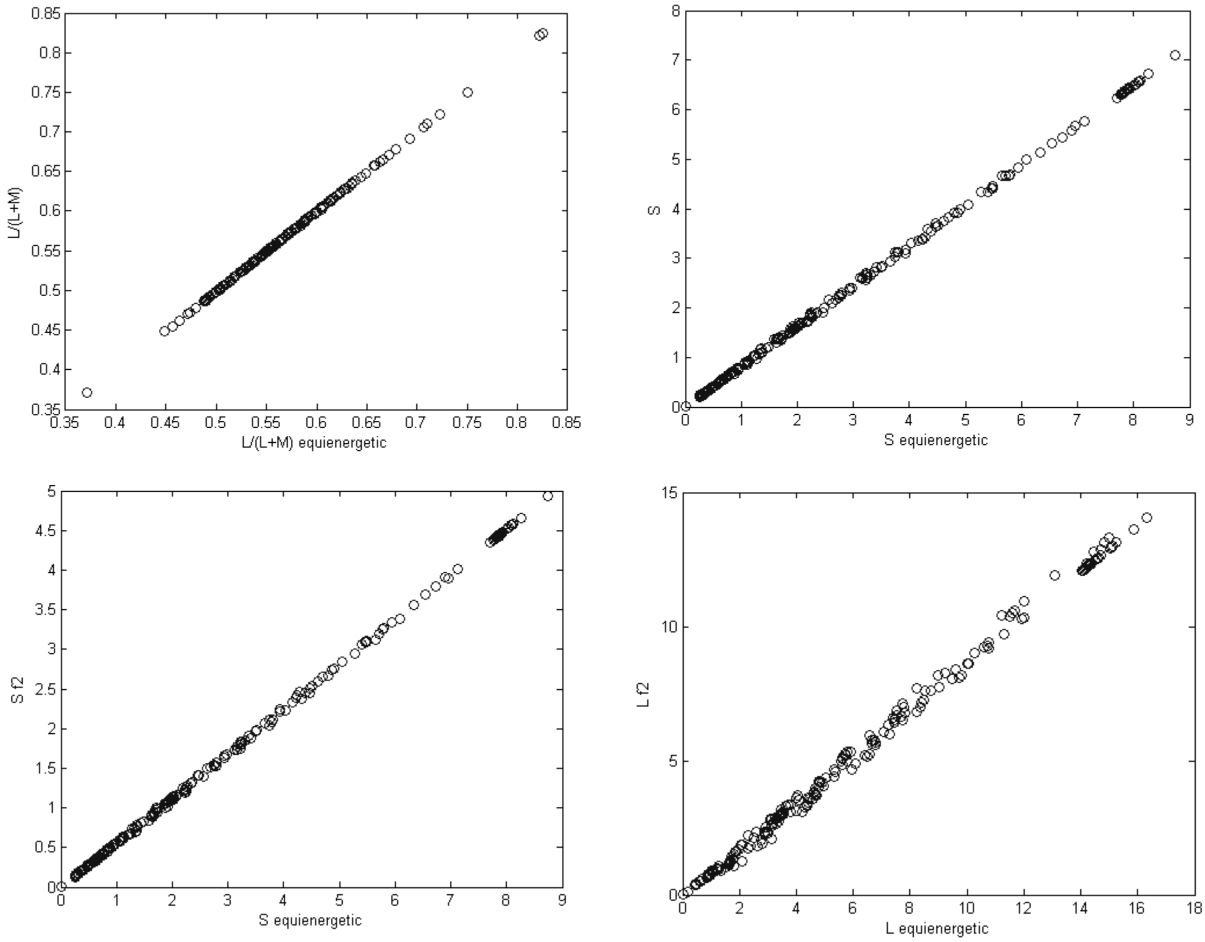

Figure 1: Some examples for artificial objects of cone-signal and second-stage-signal ratios.

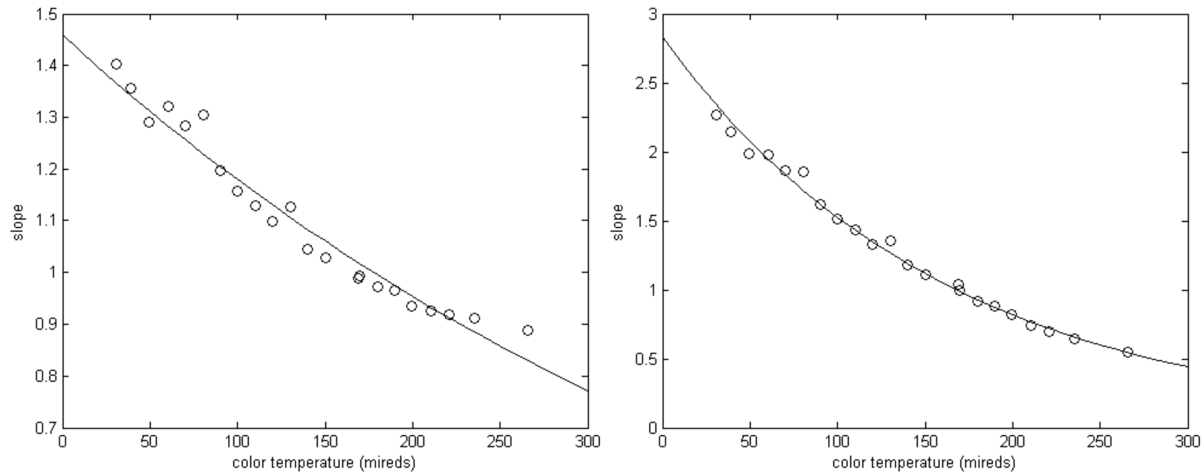

Figure 2: Examples of the dependence of cone-signal ratios with color temperature of daylight. Left: S-cone signal (natural objects). Right: L+M+S signal (artificial objects).

We studied the dependence of the slope of the straight lines with the colour temperature, finding that for cone signals of L and for L/(L+M) signals, this parameter was nearly constant with the colour temperature. The ratio of L-signal has an average and standard deviation values of 1.007 and 0.032, respectively for both natural and artificial objects. For L/(L+M) these values are 0.996 and

0.032 (artificial objects) and 1.025 and 0.035 (natural objects). Then, we can considered approximately that the excitation of L or L/(L+M) hardly changes for daylight with respect to their values for the equienergetic illuminant. For the rest of the first and second-stage mechanisms linear or exponential dependence of the slope with the colour temperature were found. In figure 2, we show some example of the results. The differences between the results for each set of reflectances (natural or artificial objects) were minimal, except in the case of S/(L+M). In table 1 we give the expression obtained in each case. Correlation coefficients obtained when adjusting these mathematical expressions were especially good (greater that 0.99) for S and S/(L+M). The reason for that can be found in the yellow-blue variation of daylight chromaticity along the day[8].

Table 1: Mathematical dependences of cone-signal ratios and second-stage-signal ratios with color temperature.

M	Natural objects	**1.28exp(-0.0013T)**
	Artificial objects	**1.30exp(-0.0013T)**
S	Natural objects	**2.83exp(-0.0062T)**
	Artificial objects	**2.84exp(-0.0063T)**
S/(L+M)	Natural objects	**-0.0059T+2.00**
	Artificial objects	**-0.0028T*1.42**
(L+M+S)	**Natural objects**	**1.41exp(-0.0019T)**
	Artificial objects	**1.46exp(-0.0021T)**

For the artificial illuminants, we found very good regression coefficients (greater than 0.99) in the straight lines adjusted for L, M, S and L/(L+M). For the rest of the parameter correlation coefficients are always greater than 0.94. In table 2 we show the values of the slopes obtained. In the case of these kinds of illuminants we can conclude that a very good constancy of cone-ratio is found similar that found for natural illuminants. For the fluorescent illuminants, however, we were unable to deduce from their correlated colour temperature values, the value of the slope of the straight lines, according to the previous equations formulated. For these illuminants normalization was also done to the SPD value at 560 nm.

Table 2: cone-signal ratios and second-stage-signal ratios for artificial illuminants.

	F2	**F7**	**F11**	**A**
L	0.874	1.069	4.975	1.055
M	0.838	1.125	4.703	0.955
S	0.564	1.165	3.044	0.657
L/(L+M)	0.791	0.925	0.928	1.032
S/(L+M)	0.957	1.059	0.948	0.807
(L+M+S)	0.792	1.111	4.443	0.930

Finally, the preliminary results found on applying our results to colour images are satisfactory. We have compared an original image, obtained when for a multiespectral image from Nascimento et al.[4] we multiplied the spectral reflectance of each pixel by a SPD (daylight or artificial), and a image obtained by the mathematical expression previously reached. In the figure 3 we shown the histogram for one case, of the CIELAB color-difference-formula values, when is compared the color of the images pixel a pixel. The average value of the color-difference for this example is 2.6 CIELAB units, which is less than the color tolerance admitted for color images differences[6] (3 CIELAB units). Similar results were obtained for the rest of natural and artificial illuminants. Although, the reproduction of images is not perfect, the synthesized image can be perceived almost identical to the original.

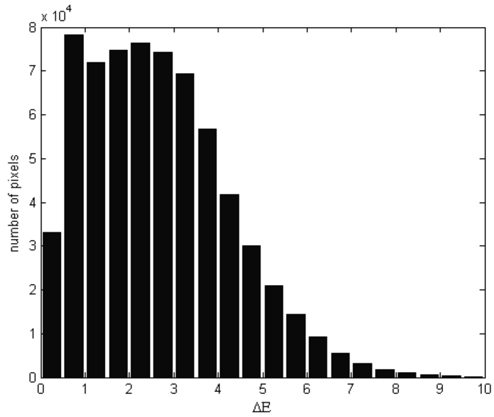

Figure 3: Histogram obtained of the CIELAB differences pixel a pixel for a scene with artificial objects and daylight. Average value 2.7 CIELAB units, standard deviation 0.2 CIELAB units.

3. CONCLUSIONS

Linearity of cone-signal ratios when the illuminant changes can be used for synthesizing color images. The mathematical expressions obtained for daylight changes allow us to predict color images seen under daylight of a certain color temperature from the cone values in the image seen under daylight of different color temperature. Also, linearity of cone-signal ratio holds for artificial illuminant, as fluorescent sources. At present, we continue this work by testing other kind of sensors such as CCD-camera sensors.

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