Loss of Spectral Information in the Colour Signals Filtered by the Human Visual System

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Abstract

Different authors have studied the response of the human visual system (HVS) in the chromatic frequency domain and have obtained its *spectral modulation sensitivity function (SMSF)*, either computationally[1] or experimentally.[2,3] The Fourier analysis applied to the colour signals (product of the spectral power distribution of the illuminant and the reflectance or transmittance function of an object) carries out the chromatic frequency domain. The SMSF defined in this domain is analogous to the CSF or the TMTF, which are defined in the spatial and temporal domains, respectively.[1-3] We have studied how HVS processes chromatic information of daylight and natural objects. The analysis of the original and filtered colour signal with different cut-off frequencies reveals some degree of degradation of these colour signals. This is particularly important when the colour signal are characterised by peaked spectral power distributions.

Introduction

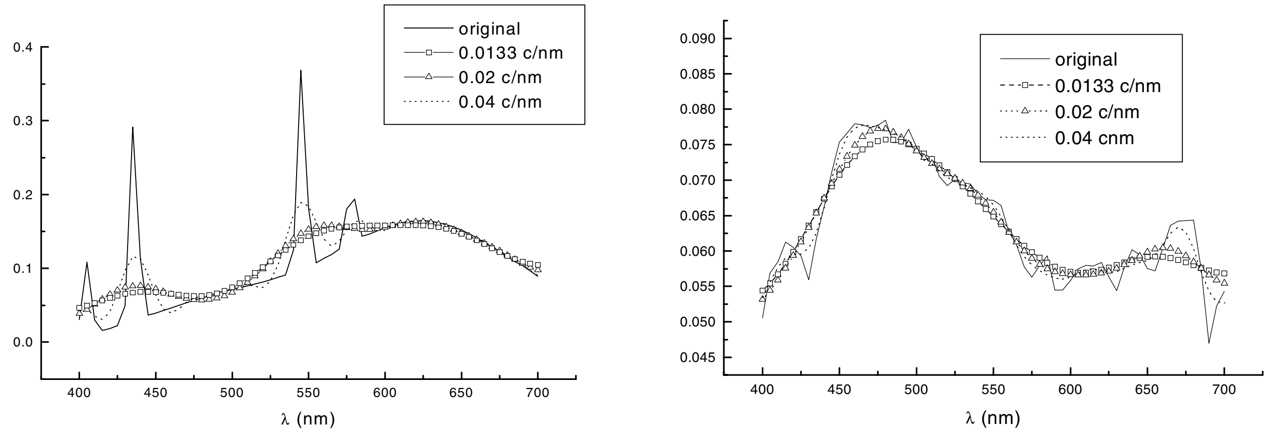
It is well known that the spectral information from colour signals is lost at receptoral levels. Nevertheless, the study of the HVS as spectral information processor can provide an interesting hypothesis of the processing of colour signals. Can the HVS's response be the same for two non-metamer colour signals with different spectral content? And, if the answer is yes, to what extent? We have analysed these questions for colour signals derived from daylight and fluorescent illuminants. These illuminants were characterised by spectral power distributions that show pronounced peak values and absorption bands. Since HVS filters all the high chromatic frequency content, it is easy to postulate that the information of these maxima and minima peak values will be lost, and the obtained colour signal should be an indistinguishable smooth version of the original one.

Bonnardel and Maloney[4] have studied how HVS transmits the spectral information of daylight and natural objects. They analysed the Fourier transforms of the corresponding colour signals and found that the relevant spectral information was below 5 c/300nm. This frequency is very similar to that found for the SMSF's cut-off frequency in a previous work.[2] Our aim here is to show the spectral loss of chromatic information instead of analysing what the HVS preserves of it. Following on from this we have chosen a set of illuminants that are characterised by a relatively high content of chromatic frequencies.

Methods and Results

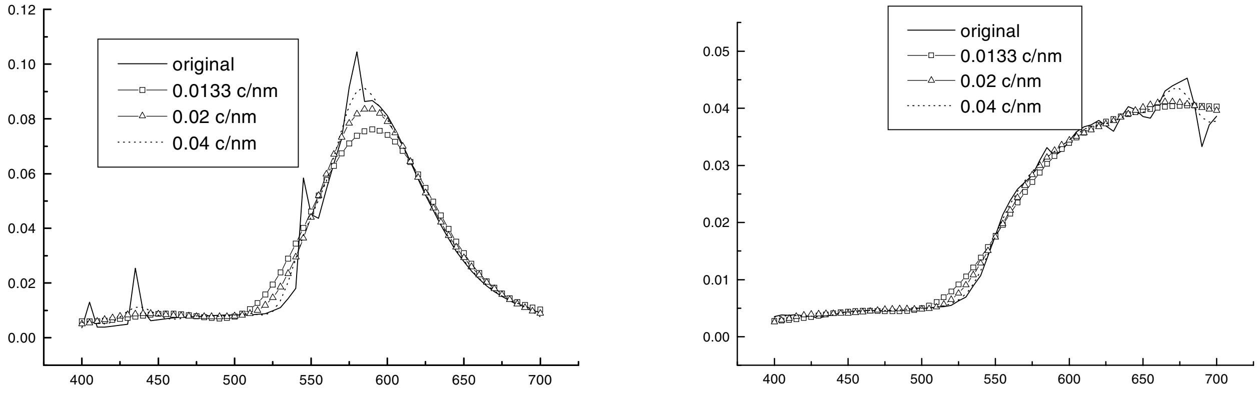
We have selected two different groups of colour signals. The first one comprises the colour signals obtained from the F_1- and F_{10}-fluorescent illuminants, one commercially available fluorescent illuminant (which was measured in our lab), the A-illuminant, and one daylight spectral power distribution (which was measured at Granada, Spain[5]). The second one comprises the colour signals derived from the multiplication of the above illuminants and the spectral reflectance function of five natural objects.[6] Next we compared the original colour signal and the filtered version in the chromatic frequency domain; parabolic filters of different cut-off frequencies (0.04, 0.02 and 0.0133 c/nm) were used to obtain the filtered colour signals. The original and the filtered signals were compared via a colour-difference formula and MacAdam's units.

Some examples of the results are presented in figures 1 and 2. For cut-off frequencies below 0.02 c/nm, the chromatic information derived from the absorption bands and the maximum emission peaks is almost lost. Also for the colour signals filtered at 0.04 c/nm the maxima and minima are sufficiently smoothed. Figure 2 shows the same object reproduced under two different illuminants. We can see that the loss of spectral information is notorious. Based on the Whittaker-Shannon theorem, a 0.02 c/nm band-limited function can be sampled at a frequency of 0.04 c/nm, which means that the sampled maxima and minima data separated less than 25 nm will be smoothed and diluted its corresponding spectral information.



(a) (b)

Figure 1. Original (solid line) and reconstructed SPD of (a) a commercial fluorescent light and (b) daylight obtained with different cut-off frequencies.



(a) (b)

Figure 2. Original (solid line) and reconstructed colour signals obtained with different cut-off frequencies for an orange-yellow object, which was reproduced under (a) a commercial fluorescent light and (b) daylight.

Table 1. Colour differences, which are expressed in MacAdam units, between the original and the filtered colour signals (illuminants).

Frequency (c/nm)	Daylight	com.fluoresc	F1	F10	Ilum. A
0.04	0.13	0.70	0.67	1.15	0.06
0.02	0.56	1.74	2.50	4.37	0.23
0.013	1.47	2.34	4.41	6.84	0.58
0.0033	18.46	24.29	11.22	10.51	7.16

Table 1 shows the colour differences obtained for each of the illuminants and cut-off frequencies used (an additional frequency of 0.0033 c/nm has been also included). Results show that the filtered version of the colour signals are below the colour tolerances (3 MacAdam units), and suggest that this smooth signals will be indistinguishable from the original ones. Only for the F_1- and F_{10}-fluorescent illuminants colour differences raise but they are always below 10 MacAdam units, which is usually adopted as an "admissible" colour difference. The results also show that the relevant spectral information is not preserved for the cut-off frequency of 0.0033 c/nm. This disagrees with the results found by Bonnardel and Maloney[4] for daylights. Nevertheless our results are not conclusive to this respect since we have used only one daylight spectral power distribution.

Table 2. Colour differences, which are expressed in MacAdam units, between original and filtered colour signals (product of the illuminants and the reflectance function of a red object).

Frequency (c/nm)	Daylight	com.fluoresc	F1	F10	Ilum. A
0.04	0.43	0.21	1.08	2.80	0.26
0.02	1.73	0.90	4.65	4.82	1.10
0.013	3.87	2.65	16.27	19.46	2.65

Table 2 shows the colour differences derived from one object and the illuminants used above. The filtered colour signals at 0.02 c/nm lead to colour differences below the admissible values, which means that the smoothed recovered signals will be indistinguishable if the HVS compared them with the original ones at this 5 nm resolution. The results for the fluorescent illuminants at low cut-off frequencies (0.0133 c/nm) are not satisfactory and there is an important loss of spectral information.

Discussion and Conclusions

The study of the human visual system's response in the chromatic frequency domain have lead to some interesting results.[1,2,3,7] Previous measurements of the spectral modulation sensitivity function (SMSF) have found a cut-off frequency around 8 c/400 nm (0.02 c/nm). If we inquire into the processing of colour signals, we might consider that the visual system acts as a chromatic processor that relates an incoming colour signal, which is filtered by the SMSF, to the final response, which is the colour perceived by observers.

The results presented here confirm that the HVS filters the spectral information in the chromatic frequency domain. Thus the original colour signals are equivalent to those band-limited versions at 0.02 c/nm, which are characterised by a smoothed spectral profile. So, the spectral information linked to the emission peaks and the absorption bands disappears, and the results suggest that the HVS smoothes the daylight and the artificial illuminant spectral power distributions when chromatic information is processed. Since the SMSF is a band-pass filter, this suggests the possibility of using these experimental data as an alternative to the low pass filter employed here.

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Biography

Javier Romero, Ph.D., is a full professor in the Department of Optics at the University of Granada since 1993. Juan L. Nieves, Ph.D., is an associate professor since 2001 in the same department. Eva Valero obtained her Ph.D. in 2000 and is an assistant professor at the University of Granada. Javier Hernández-Andrés, who received his Ph.D. in 1999 is also an assistant professor in the same department. José A. García, Ph.D., is an associate professor since 1991 at the University of Granada. All of the authors are mainly involved in research on colour vision, applied colorimetry, and, more specifically, on colour constancy, spectral reflectances and daylight spectral measurements.