The Estimation of Natural Reflectances By a Cone-Based Linear Mode

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Maloney (1986) reported that 3 basis functions, derived from principal components analysis of the reflectances of Munsell papers, can account for >99% of the variance (from black) in a set of natural reflectances. This raised the possibility that a trichromatic visual system can generate accurate estimates of the reflectances in natural visual scenes. To address this question, a set of 377 reflectance spectra from natural objects (leaves, flowers, and fruits) was collected. (Note that Krinov's reflectances, used in Maloney's and others' studies, represent the space-averaged reflectances from large natural formations, not the reflectances of individual colored objects). The responses of human cones to these natural surfaces was calculated using the cone sensitivities from Stockman et al. (1993). Because these cone sensitivities are not necessarily related to the principal components of the reflectances, a Cone-Based Linear Model (CBLM) was developed for this analysis (R. O. Brown, 1993 OSA Annual Meeting). The CBLM provides a least-squares best fit to the natural reflectances, using the 3 cone responses as coefficients. The CBLM was compared to 2 linear regression models, which are based on the 3 principal components from either the Munsell reflectances (LR-M) or the natural reflectances (LR-N). All these analyses assumed a constant, known illuminant (CIE Source C), and covered the range 400-650 nm.

Conclusions

1. The spectral reflectances of individual natural objects vary much more steeply with wavelength, and span a much larger gamut chromaticities, than the spectral reflectances of natural formations in Krinov's set.

2. The CBLM captured roughly 85% of the spectral variance from the mean in the natural reflectances studied. (Note: measuring variances from the mean gives considerably lower R^2 estimates than measuring variances from black, as in Mahoney's study.)

3. Linear regression with the 3 principal components derived from the natural reflectances (LR-N) was only slightly better than the CBLM, capturing roughly 87% of the spectral variance. This was a surprisingly small difference, since linear regression allows the arbitrary selection of coefficients based on complete knowledge of the reflectance spectra to be fit., while the CBLM is constrained to use the 3 cone responses as its coefficients. (Note that the CBLM, but not LR, is a solution to the inverse problem)

4. Linear regression with the 3 principal components from the Munsell papers (LR-M) was considerably worse, capturing only about 65% of the spectral variance in the natural set. Of course the LR-M model was superior to the LR-N model for fitting the Munsell paper reflectances. This indicates that knowledge of the class of surfaces in a scene (i. e. natural objects, colored papers, etc.) can significantly improve the reflectance estimates.

5. In linear regression models, reflectance estimates are generally not metameric with the original stimuli, and visually metameric stimuli produce a family of distinct reflectance estimates. In the CBLM, all the reflectance estimates are metameric with the original stimuli, and all visually metameric stimuli produce the same estimate. (In other words, a grey surface generates a metameric grey reflectance estimate in the CBLM, but might generate a purple or green reflectance estimate in linear regression.)