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Image Noise Propagation in Multispectral Image Capture

Peter D. Burns (Eastman Kodak Company, Rochester, NY 14650-1925)

Evaluation of multispectral (more than three-color records) image capture is usually expressed in terms of the accuracy of image detection and signal processing. Practical systems, however, are subject to both random pixel-to-pixel and calibration error. In this talk the precision of a camera and associated signal processing is addressed from the standpoint of image noise introduced by image detection. For applications not requiring simultaneous acquisition of all records, acquiring several frames using a set of spectral filters can form a multispectral camera. Our system used a set of seven commercially available filters with a monochrome digital camera. Principal component analysis was used to reconstruct sample spectral reflectance curves from camera signals.[1] A least-square matrix, **M**, was calculated to allow the seven camera signals, to be transformed to estimates of the scalar coefficients associated with the eigenvectors. The spectral reconstruction from n camera signals, $\mathbf{s}^T = [s_1, s_2, ..., s_n]$, using m eigenvectors, $\Phi^T = [e_1, e_2, ..., e_m]$, is given by

$$\mathbf{f} = \Phi \mathbf{M}\mathbf{s}$$

where **f** is the reconstructed reflectance vector. This was done for each pixel. For specified viewing conditions the CIE tristimulus values, or other color encoding of the pixel values, could then be computed.

All electronic image detectors are subject to stochastic error due to, e.g., photon arrival statistics (shot noise), thermally generated electrons, and readout electronics. Because the signal processing involved matrix operations, the covariance matrix provided a natural set of second-order statistics for computation. Error propagation analysis[2] then provided a way of predicting the transformation of the first- and second-order image noise statistics from image detection to transformed color signal. This was applied at each step of the image-processing path. The most general approximation to nonlinear multivariate error propagation used the Jacobian, or derivative, matrix. For example, if the pixel tristimulus values are expressed as a vector, $t^T = [X, Y, Z]$, and the CIELAB coordinates are, $c^T = [L*, a*, b*]$, and the (3 x 3) covariance matrix, Σ, the image noise statistics are transformed by,

$$\Sigma_c \cong \mathbf{J} \Sigma_t \mathbf{J}^T,$$

where **J** is the (3 x 3) derivative matrix.

Results of the analysis were found to agree with experimental results, allowing the comparison of system colorimetric precision with error due to, e.g., signal quantization. In addition, combining source modeling and error propagation allows us to predict the performance of various designs. The approach taken is also applicable to three-color image acquisition and processing.

[1]. P. D. Burns and R. S. Berns, ‘Analysis of Multispectral Image Capture,’ *Proc. Fourth Color Imaging Conf., IS&T/SID*, 19-22 (1996).
[2]. P. D. Burns and R. S. Berns, ‘Error Propagation Analysis for Color Measurement and Imaging,’ *Color Research and Appl.*, 22: 280-289 (1997).

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