Optimization of total multispectral imaging systems: best spectral match versus least observer metamerism

Bernhard Hill

Department of Electrical Engineering and Information Technology
Aachen University of Technology
E-mail: hill@ite.rwth-aachen.de

Abstract

The paper deals with total multispectral imaging systems assembled from a multispectral camera or scanner for capturing color images or natural scenes and a multichannel color image display for image synthesis. The multispectral scanner delivers N narrow-band spectral separations of an image via an N-channel output and the multichannel display is considered to compose color images by the superposition of M narrow-band color channels.

The aim of the multispectral technology is to reproduce an approximation to the spectral color stimuli of the colors of an original image in order to reduce color mismatches between original and reproduction for any human observer and for arbitrary illuminants considered. The system is studied and developed for softproofing and image transmission applications. Original scenes or objects like goods, commercial products, image documents, art paintings, textiles and so on shall be reproduced on a screen in "true color" simulating the appearance under different illuminants supposed to irradiate the original scenes or objects.

The analytical model of the system assumes the multispectral camera to be characterized by N narrow-band spectral responsivity curves constituting a set of spectral analysis functions. So, the N camera channels deliver N signals representing sampling values of input spectra. The camera is usually calibrated by a white object as reference. Accordingly, the sampling values are normalized with reference to illuminant E and therefore represent the spectral reflection of object colors. The multichannel display at the system`s output is assumed to compose colors by the superposition of M spectral lights from M channel composers characterized by spectral power distributions. These M power spectra form a set of spectral synthesis functions with their intensities controlled by the M input signals of the display.

There are two methods considered to control the M channels of the display by the N channels of the camera. The first method called "direct control" uses an N x M linear mapping matrix derived from an optimization procedure [1]. This configuration is typical for closed system applications. As the output signals of the multispectral camera are normalized with respect to illuminant E in general, the calculation of the elements of the mapping matrix has to take into account an illuminant supposed to irradiate the original objects. The second method useful for open system applications [1] starts with an estimation of an original color stimuli from the sampling values of the camera using e.g. Wiener inverse, smoothing inverse or eigenvector analysis. The result represents an approximation to the spectral reflection of an original object color. In this stage which represents an open interface, the spectral radiating power function of an arbitrary illuminant supposed to irradiate the original object in a practical scenario can be introduced. Afterwards, the discrete values representing the spectrum are mapped onto the M channels of the display, again using an optimized linear mapping matrix. This second method provides more flexibility than the first one with the advantage that only one matrix has to be calculated for any illuminant considered whereas the first method has to use different mapping matrices for different illuminants. Anyway, the main question in both cases is how to optimize the elements of the mapping matrices to get the best reproduction of colors.

The answer to the question requires the definition of a quality measure for the reproduction. As a first quality

measure, the best spectral match in the visible range of the spectrum might be a reasonable goal. This is realized by calculating a general expression for the reproduced spectra from the system`s model and applying a mathematical method to minimize the average squared mismatch between reproduced and original spectra for a set of spectral test data.

However, the best spectral match of the reproduced color stimuli does not automatically lead to smallest mismatches between input and output colors perceived by human observers. Therefore, an alternative method has been studied which considers a selected number of human observers comparing the perceived color pairs captured and reproduced by the multispectral system under a given illuminant. The human observers are described by their color matching functions and the optimization aims at smallest average or smallest maximum color mismatches for a given set of test spectra. This method minimizes the observer-oriented metamerism of the system for any given illuminant.

To compare the method of best spectral matching with the method minimizing the observer metamerism, the same set of observers for the same set of test spectra is applied to check the reproduction quality of both system configurations. Average color mismatches as well as largest and 1% largest errors in terms of CIE ΔE94 color differences are investigated. It turns out that the method of observer-oriented optimization leads to better results if illuminants with smooth power spectra are considered. Only for the case of illuminants providing large spikes, the differences are not so stringent. When comparing the spectral match of input, interface- and output spectra, the method of best spectral matching results in smaller mismatches across the complete visible range whereas in case of the observer oriented method the spectral approximation is more accurate within the range of largest "sensitivity" of the matching functions of the observers and less accurate in the range beside.

The paper will present and discuss results derived from an idealized system model with an arbitrary number of N camera channels and M display channels for different reference illuminants. The reproduction quality is checked by 24 observers defined from published measurements of 2^o and 10^o color matching functions [2]. The spectral data set of Vrhel was used for optimizing the system and calculating the reproduction quality [3].

An experimental system using a 16-channel multispectral camera and a 6-channel display has been realized in the laboratory. Results provided by this system take into account the experimental responsivity functions of the camera and the practical spectral synthesis functions of the display. The channels of the display are separately linearized via look-up tables. It will be shown that the observer metamerism and the overall color mismatches can be made very small even by this reproduction system with only 6 display channels.

References

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