Multispectral Imaging

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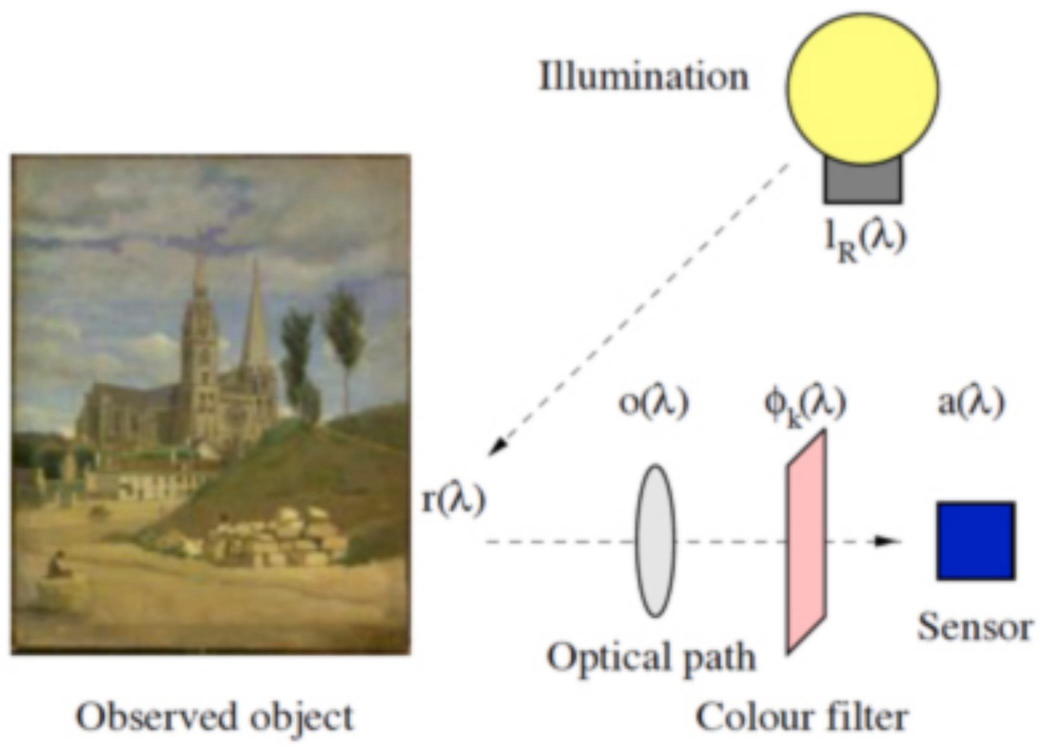
Summary

Spectral reconstruction or spectral recovery refers to the method by which the spectral reflectance of the object is estimated using the output responses of the acquisition channels. Most of the algorithms are based on a linear optical model and additive noise. The acquisition responses are the integration of all of the light energy that reaches the sensor, weighted by the sensitivity of each channel. The channel sensitivity is the result of filter transmission and the sensitivity of the detector. Once the model is defined, the reflectance factor can be estimated for each pixel after deriving the model's parameters.



The optical path of light reaching to the sensors of the acquisition system [10].

In most cases, solving the equations for estimating the reflectance factor leads to an ill-posed problem in which the solution for spectral reflectance is not unique [11, 12]. A variety of mathematical and statistical models have been introduced for better spectral estimations, according to the statistical traits of the specimen being examined and technical properties of the capturing unit.

Considering the multispectral systems available, the spectral estimation algorithms can be divided into two main categories. In the first category, different parts of the imaging system are characterized physically and independently, requiring specific laboratorial equipment and measurement techniques. In the second type of solution, spectral reflectances are estimated using statistical models also known as empirical or learning-based methods. In target-based reconstruction methods, the spectral reflectance of the samples is derived from a series of training data with known spectral information. This method is useful when the spectral sensitivity of the detector is not accurately available. In this section two examples of target-based reconstruction methods are introduced.

MCSL Dual-RGB Multispectral Acquisition System

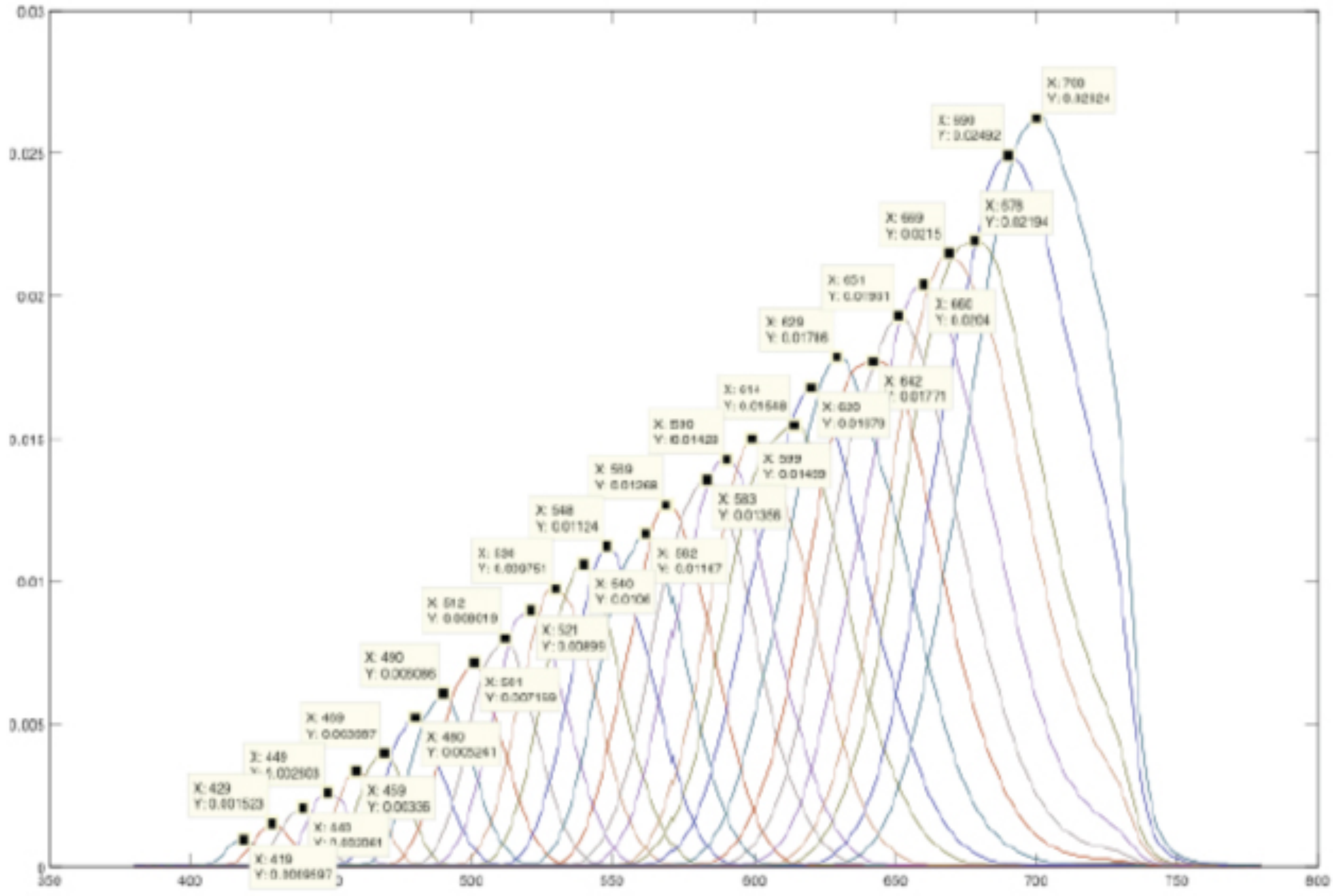
The image capturing system included a high-resolution camera with ability of capturing images through two blue and yellow filters. Two images were takes in a sequence of time after changing the filters. As a result, the capturing system provides 6 (or 5 practical) subsampling of spectral radiance for further spectral reconstructions. Different sorts of spectral reconstruction methods (such as PCA, pseudo inverse, Wiener transformation and Matrix-R) can be used for spectral reconstructions. The workflow of using PCA method for spectral reconstruction is shown in the following plot [1, 4, 8, 9].

In this figure, the PCA coefficients corresponded to the first nine most significant eigenvectors are related to the Dual RGB of a standard target using an optimization process. After optimizing the 6x9 matrix, the spectral reflectance of the surface can be estimated by given six-channel RGB image.

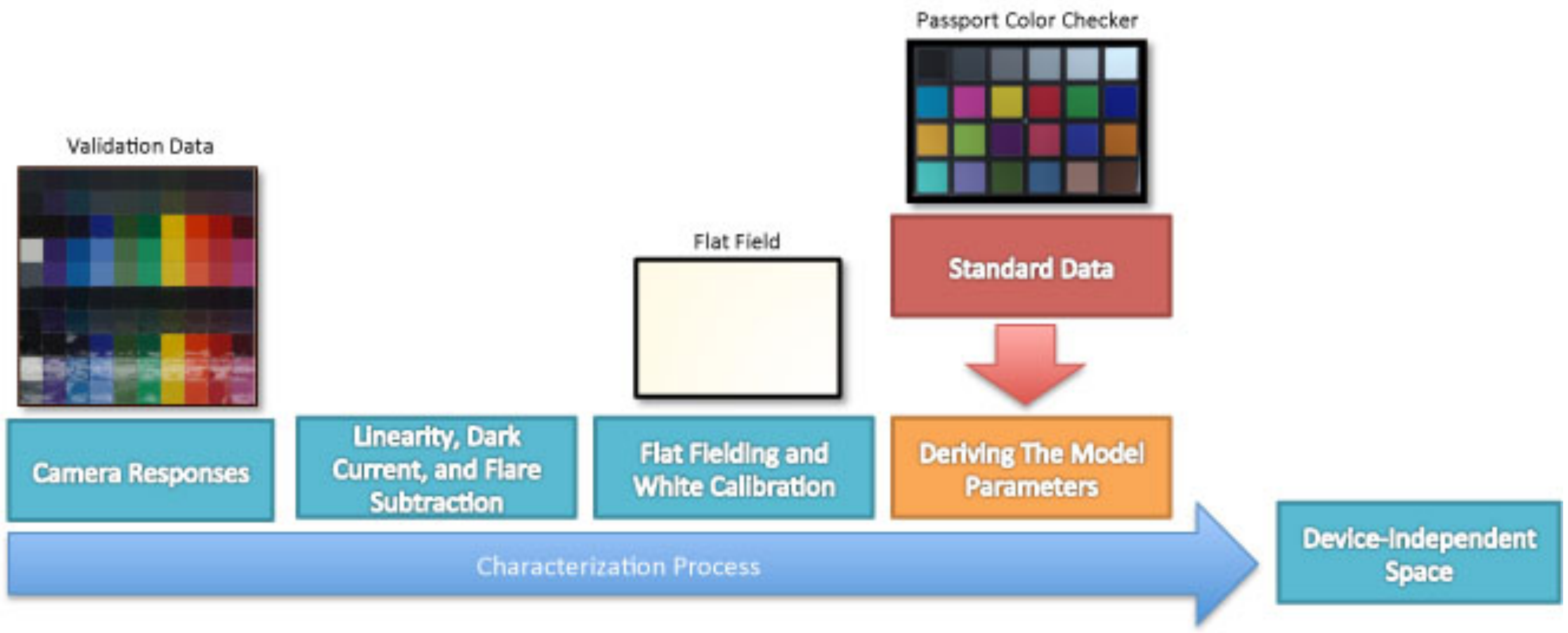
LCTF-Based Acquisition Sytem

Spectral Characterization and Measurement

More accurate alternative of spectral measurement is yield using a series of narrow band filters across the visible range. Liquid Crystal Tunable Filters (LCTFs) provide a convenience way for these sorts of capturing platforms. In case of enough numbers of filtering, the spectral reflectance of the surface can be directly estimated. A set of typical transmission curves against wavelength (nm) of LCTFs is shown in following plot.



A terget-based spectral characterization algorithm was chosen for converting camera signals to physical spectral reflectances.

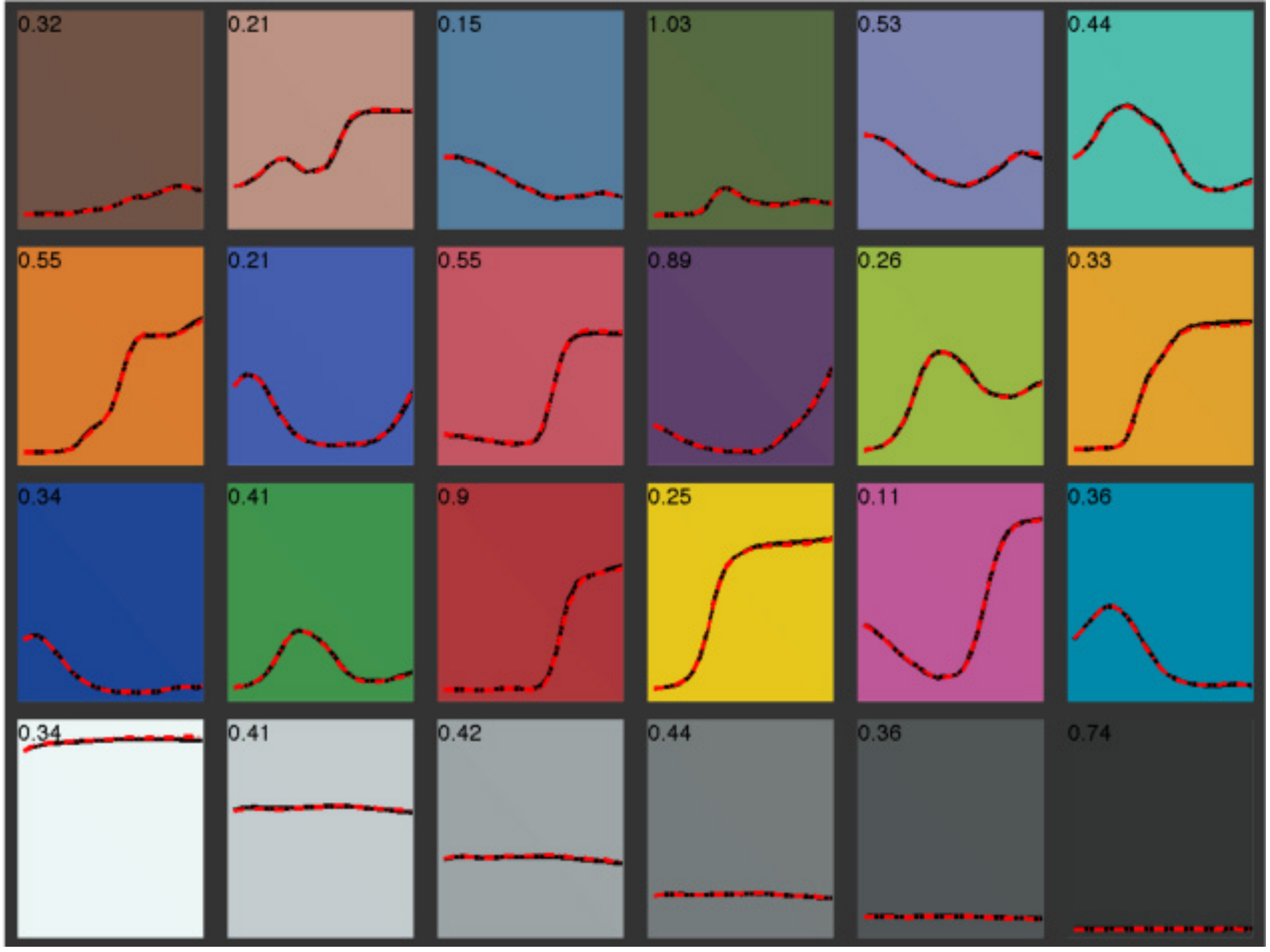


In practice, the whole system was characterized according to the spectral reflectances from an xrite i1 spectrophotometer. The characterization workflow particularly were corrected for dissimilarities of geometry differences of the spectral camera and spectrophotometer. The LCTF angular dependency of the measurements was also taken into account and corrected.

Following is the spectral and colorirmetric comparisons of the actual and estimated spectral reflectances for training and validation training sets. Solid black lines and dashed red lines indicate the actual and estimated spectrals correspondingly. Numbers on the top left are average CIEDE2000 for each sample. Each rectangular patch is consist of to upper and lower triangle as a colorimetric reproduction of actual and estimated patches.

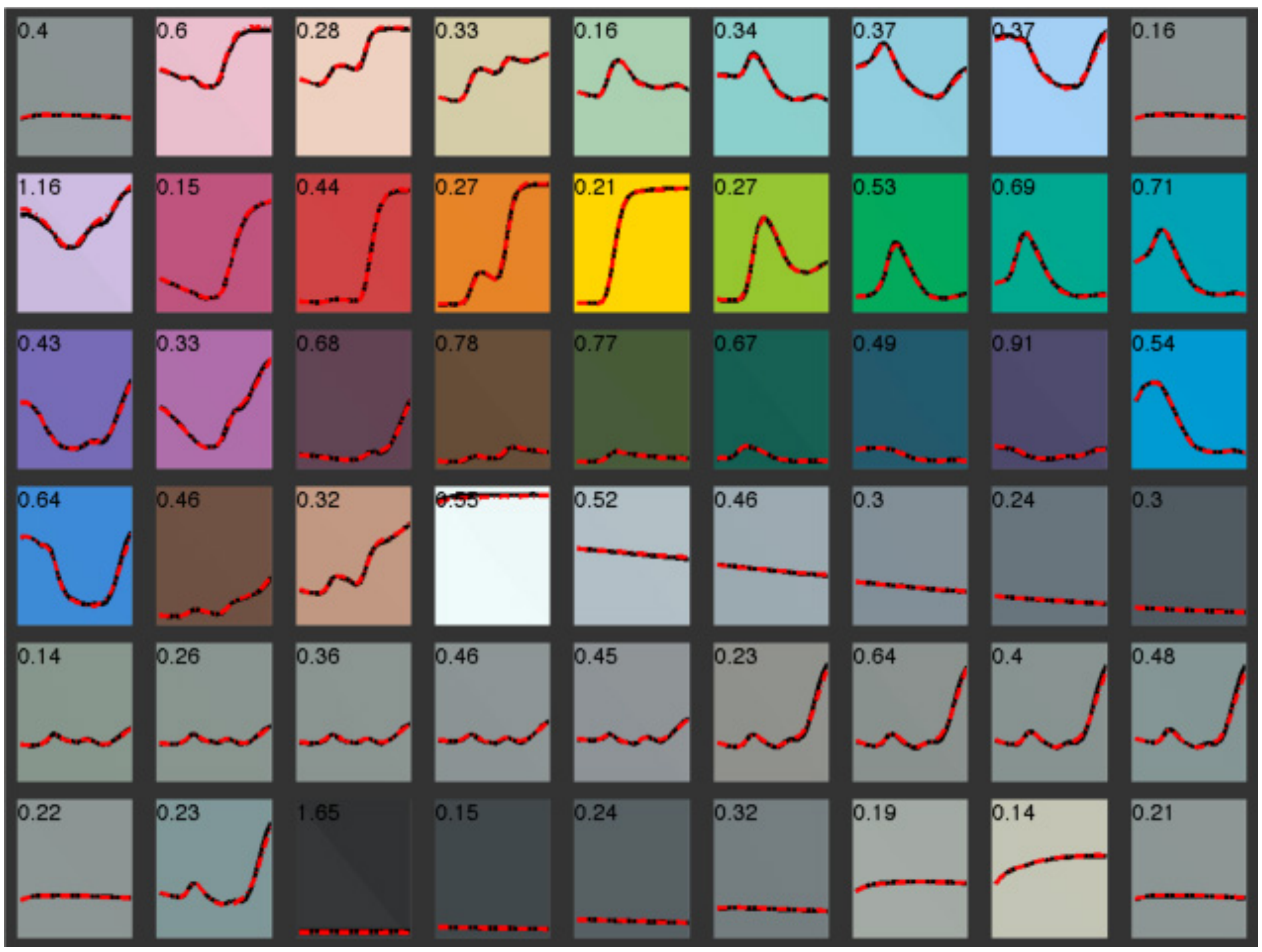
The following tables summarize the colorimetric and spectral reflectance RMSs for different error metrics and for different characterization steps.

Training Dataset - Xrite ColorChecker Passport



	CIEDE2000				Spectral RMS			
	Mean	Max	Variance	90p	Mean	Max	Variance	90p
Raw Image	8.01	11.95	4.45	10.13	0.11224	0.32312	0.00487	0.19348
Dark Corrected	8.09	12.01	4.33	10.19	0.11282	0.32381	0.00488	0.19405
Flare Corrected	8.27	12.14	4.02	10.33	0.11426	0.32545	0.00487	0.19544
Flat Fielded	1.25	2.24	0.34	1.95	0.01576	0.03829	0.00010	0.02932
Angular Corrected	1.32	2.20	0.32	2.03	0.01599	0.03859	0.00009	0.02866
Flat Fielded	1.31	2.11	0.35	2.07	0.01598	0.03931	0.00010	0.02940
Spectrally Characterized	**0.45**	**1.06**	**0.06**	**0.91**	**0.00446**	**0.00803**	**0.00000**	**0.00766**

Validation Dataset - MCSL Custom Color Target



	CIEDE2000				Spectral RMS			
	Mean	Max	Variance	90p	Mean	Max	Variance	90p
Raw Image	10.68	17.67	10.87	15.08	0.15294	0.33332	0.00722	0.27145
Dark Corrected	10.76	17.77	10.81	15.16	0.15353	0.33392	0.00722	0.27207
Flare Corrected	11.29	18.48	10.47	15.80	0.15770	0.33821	0.00722	0.27652
Flat Fielded	1.01	3.36	0.32	1.67	0.01944	0.05543	0.00019	0.04191
Angular Corrected	1.06	3.35	0.34	1.74	0.02014	0.04948	0.00020	0.04297
Flat Fielded	1.04	3.33	0.34	1.59	0.02028	0.05223	0.00021	0.04282
Spectrally Characterized	**0.44**	**1.65**	**0.07**	**0.71**	**0.00774**	**0.02539**	**0.00004**	**0.01820**

Database of Spectral Images of Paintings

Find an exclusive collection of 23 spectral images measured by the LCTF capturing unit here.

PhD Dissertation

A comprehensive in-depth detail can be found in my PhD dissertation.

References

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