

Multi-spectral Image Acquisition and Spectral Reconstruction using a
Trichromatic Digital Camera System associated with absorption filters
PART Vb Spectral reconstruction in reflectance space: Targets II and III

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Target II: Set of 147 painted patches

I) Linear method using simulated digital counts (IBM DCS)

A set of 147 painted patches was imaged for various combinations of R, G, and B channels without filters and with filters (Kodak Wratten filters number 38 and 66 plus didymium filter). The results of the spectral reconstruction for 6 channels are summarized in tables I to VI.

6 eigenvectors and channels (R, G, B without filter and with Wratten filter number 38)

Table I. Spectral reconstruction using 6 eigenvectors; 6 signals (R, G, B without filter and R, G, B with Wratten absorption filter number 38).

Patch	ΔE^*_{94}	reflectance rms error factor	Metameric Index
Average	0.34	0.014	0.27
Std Dev	0.25	0.007	0.26
Max	1.26	0.031	1.36
Min	0.02	0.002	0.01

The spectral reconstruction for every combination of filters produced quite accurate colorimetric results. Since the colorimetric accuracy graph for all the patches do not produce perceptible difference in $a^* \times b^*$ plot for different combination of filters, they were omitted in this report. As an example, Figure 1 shows the colorimetric accuracy for the spectral reconstruction using 6 eigenvectors, 6 channels (R, G, B without filter and with Wratten absorption filter number 38). Instead of representing the $a^* \times b^*$ plot, the results were presented in the form of E^*_{94} histograms. The spectral and colorimetric accuracy are shown

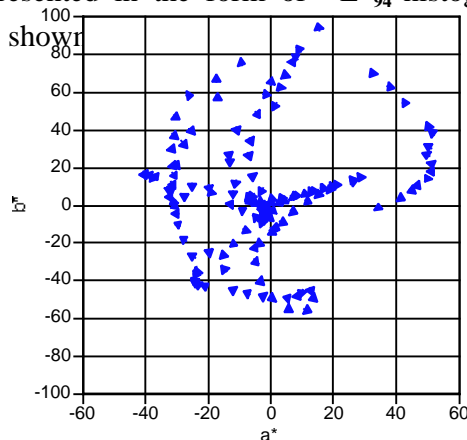


Figure 1. Colorimetric accuracy using 6 eigenvectors; 6 signals: R, G, B without filter and with Wratten absorption filter number 38; (original -> reproduction).

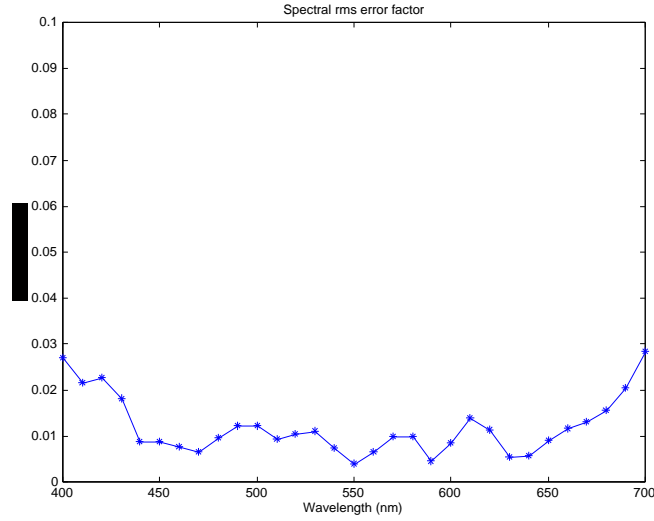


Figure 2. Spectral rms error for spectral reconstruction using 6 eigenvectors; 6 signals: R, G, B without filter and with Wratten absorption filter number 38.

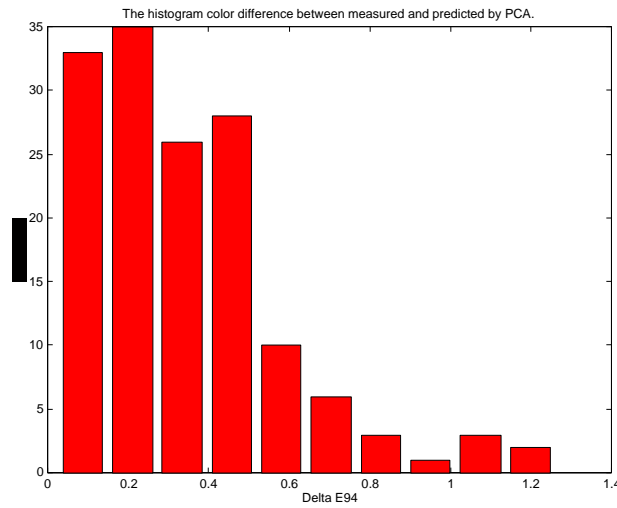


Figure 3. E^*_{94} histogram for spectral reconstruction using 6 eigenvectors; 6 signals: R, G, B without filter and with Wratten absorption filter number 38.

6 eigenvectors; 6 channels (R, G, B without filter and with Wratten filter number 66)

Table II. Spectral reconstruction using 6 eigenvectors; 6 signals: R, G, B without filter and with Wratten absorption filter number 66.

Patch	ΔE^*_{94}	reflectance rms error factor	Metameric Index
Average	0.24	0.012	0.24
Std Dev	0.15	0.006	0.21
Max	0.67	0.030	0.98
Min	0.01	0.002	0.01

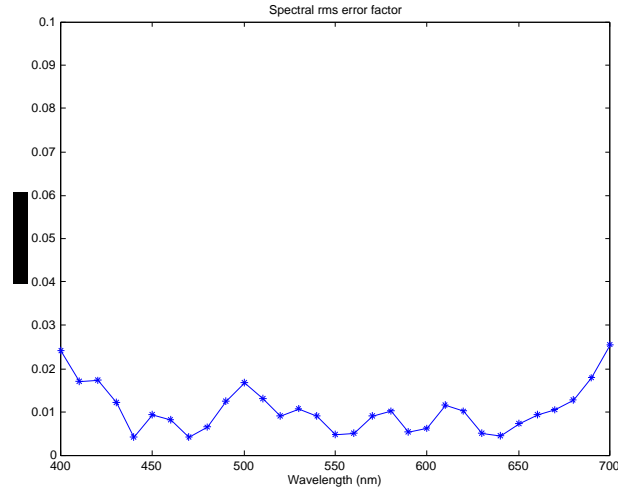


Figure 4. Spectral rms error for spectral reconstruction using 6 eigenvectors; 6 signals: R, G, B without filter and with Wratten absorption filter number 66

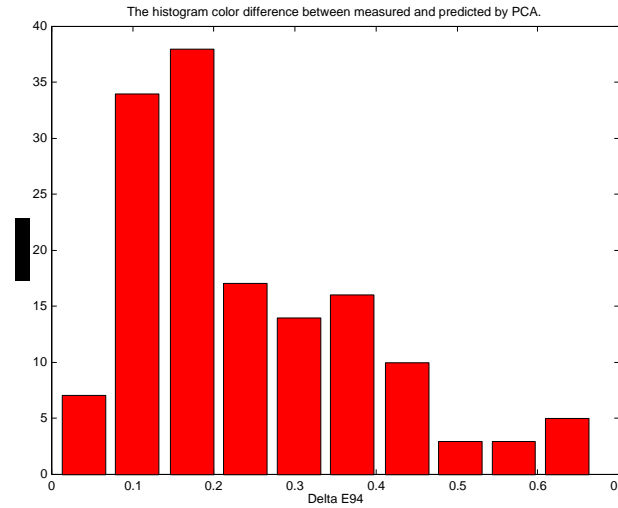


Figure 5. E^*_{94} histogram for spectral reconstruction using 6 eigenvectors; 6 signals: R, G, B without filter and with Wratten absorption filter number 66.

6 eigenvectors; 6 channels (R, G, B without filter and with didymium filter)

Table III. Spectral reconstruction using 6 signals: R, G, B without filter and with didymium filter.

Patch	ΔE^*_{94}	reflectance rms error factor	Metameric Index
Average	0.55	0.015	0.85
Std Dev	0.45	0.009	0.81
Max	2.19	0.041	3.97
Min	0.04	0.002	0.01

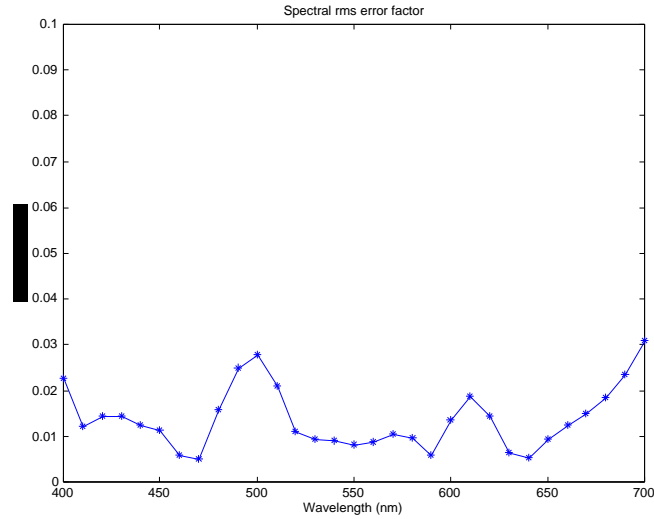


Figure 6. Spectral rms error for spectral reconstruction using 6 eigenvectors; 6 signals: R, G, B without filter and with didymium filter

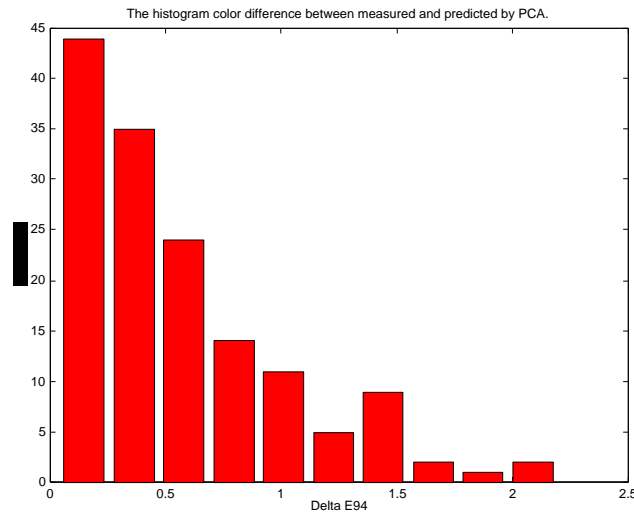


Figure 7. E^*_{94} histogram for spectral reconstruction using 6 eigenvectors; 6 signals: R, G, B without filter and with didymium filter.

6 eigenvectors; 6 channels (R, G, B with Wratten absorption filter number 38 and with didymium filter)

Table IV. Spectral reconstruction using 6 eigenvectors; 6 signals: R, G, B with Wratten absorption filter number 38 and with didymium filter.

Patch	ΔE^*_{94}	reflectance rms error factor	Metameric Index
Average	0.49	0.015	0.52
Std Dev	0.37	0.009	0.50
Max	1.60	0.046	2.16
Min	0.03	0.002	0.03

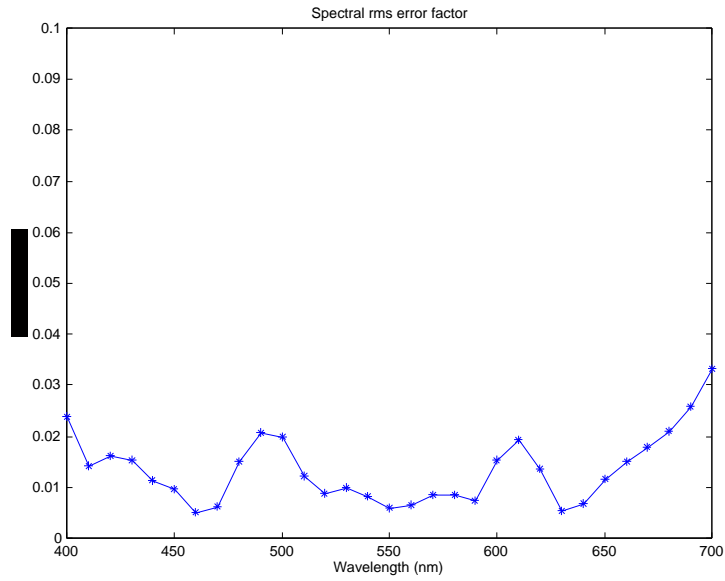


Figure 8. Spectral rms error for spectral reconstruction using 6 eigenvectors; 6 signals: R, G, B with Wratten absorption filter number 38 and with didymium filter

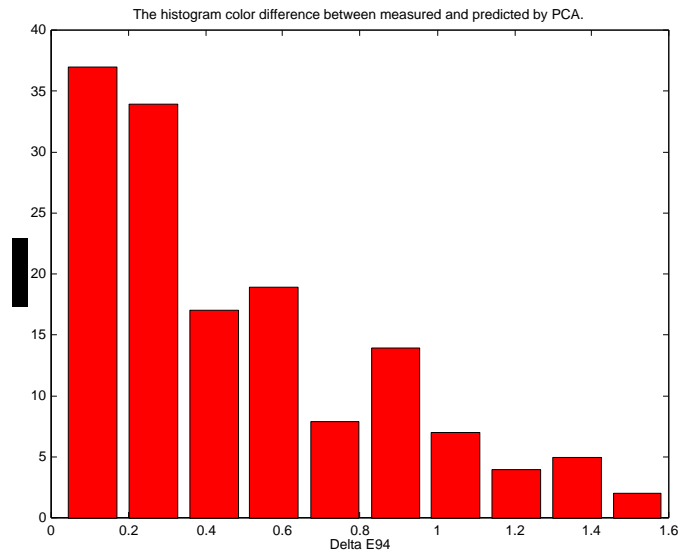


Figure 9. E^*_{94} histogram for spectral reconstruction using 6 eigenvectors; 6 signals: R, G, B with Wratten absorption filter number 38 and with didymium filter.

6 eigenvectors; 6 channels (R, G, B with Wratten absorption filters number 38 and 66)

Table V. Spectral reconstruction using 6 eigenvectors; 6 signals: R, G, B with Wratten absorption filter number 38 and with Wratten absorption filter number 66.

Patch	ΔE^*_{94}	reflectance rms error factor	Metameric Index
Average	0.33	0.017	0.25
Std Dev	0.22	0.011	0.22
Max	1.07	0.063	0.90
Min	0.04	0.003	0.01

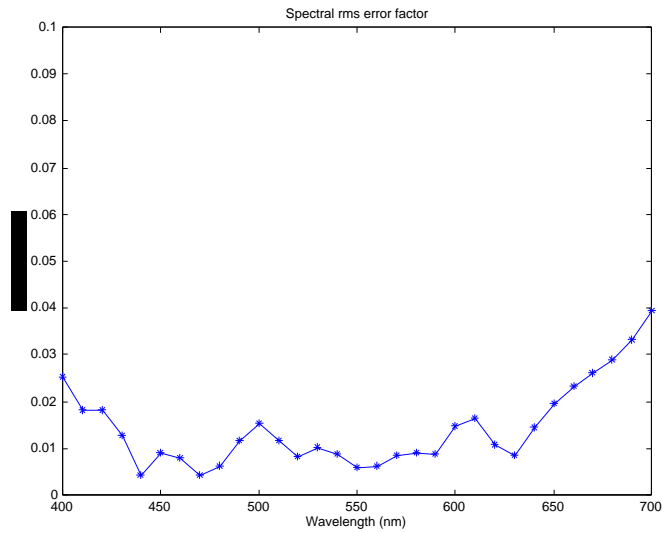


Figure 10. Spectral rms error for spectral reconstruction using 6 eigenvectors; 6 signals: R, G, B with Wratten filters number 38 and 66

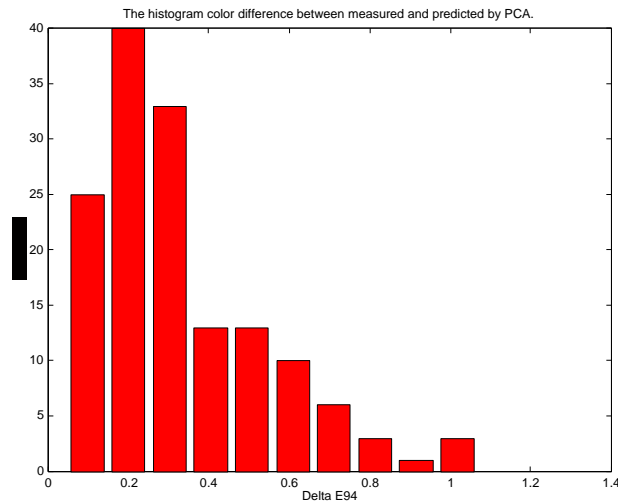


Figure 11. E^*_{94} histogram for spectral reconstruction using 6 eigenvectors; 6 signals: R, G, B with Wratten absorption filters number 38 and 66.

6 eigenvectors; 6 channels (R, G, B with Wratten absorption filter number 66 and with didymium filter)
Table VI. Spectral reconstruction using 6 eigenvectors; 6 signals: R, G, B with Wratten absorption filter number 66 and with didymium filter.

Patch	ΔE^*_{94}	reflectance rms error factor	Metameric Index
Average	0.38	0.014	0.40
Std Dev	0.27	0.008	0.26
Max	1.35	0.047	1.30
Min	0.06	0.002	0.01

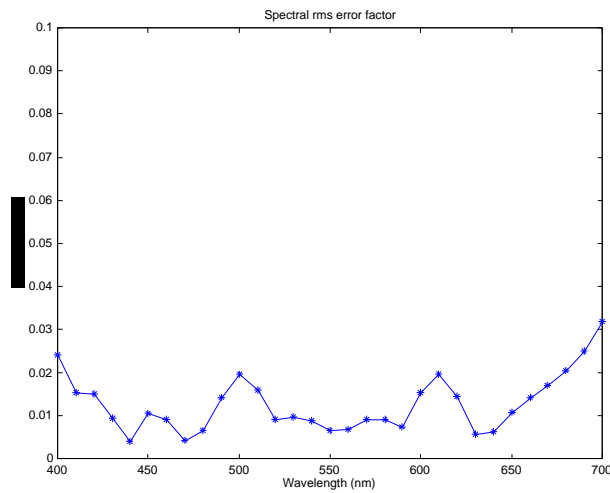


Figure 12. Spectral rms error for spectral reconstruction using 6 eigenvectors; 6 signals: R, G, B with Wratten absorption filter number 66 and with didymium filter

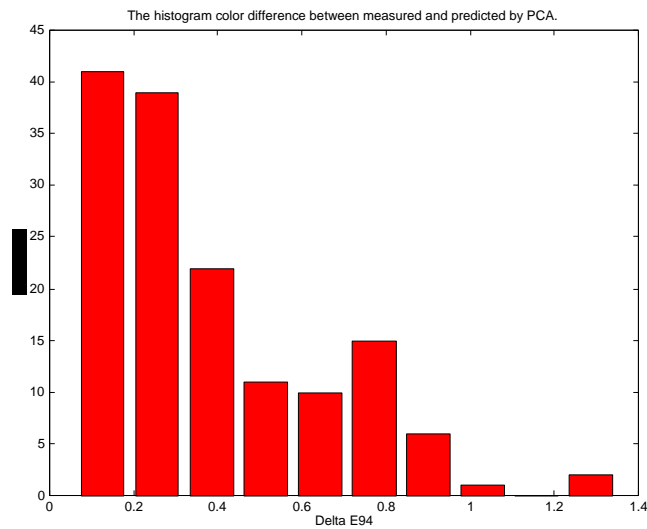


Figure 13. E^*_{94} histogram for spectral reconstruction using 6 eigenvectors; 6 signals: R, G, B with Wratten absorption filter number 66 and with didymium filter.

From Figures 1 to 13 and Tables I to VI, it is possible to see that, although all the tested filter combinations presented an acceptable range of colorimetric and spectral performances., the best overall averaged colorimetric and spectral results are obtained for the spectral reconstruction using 6 eigenvectors and 6 signals from R, G, B without filter and R, G, B with very light green Wratten absorption filter number 66 that was the same result obtained when the target results are the Macbeth ColorChecker. The results obtained for the set of 147 painted patches were better than the results obtained for the Macbeth ColorChecker.

II) Linear method using measured digital counts (IBM DCS)

This method was applied for 6 eigenvectors and 6 channels (R, G, B without filter and with Wratten filter number 66). The results are summarized in Table VII and figures 14 and 16.

Table VII. Spectral reconstruction using 6 eigenvectors; 6 signals (R, G, B without filter and R, G, B with Wratten absorption filter number 66).

Patch	ΔE^*_{94}	reflectance rms error factor	Metameric Index
Average	5.93	0.046	2.62
Std Dev	4.54	0.019	1.76
Max	29.68	0.120	9.07
Min	0.50	0.009	0.19

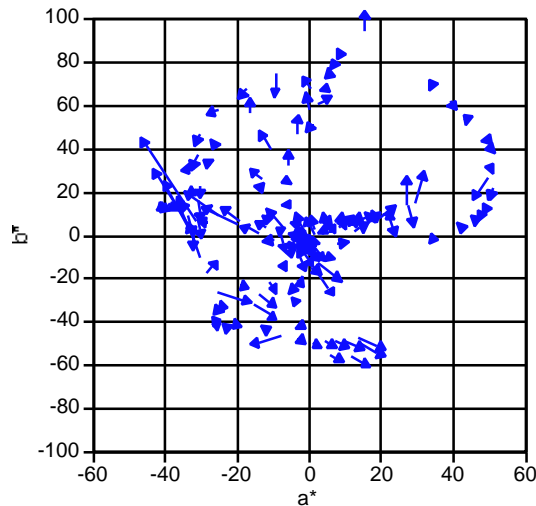


Figure 14. Colorimetric accuracy using 6 eigenvectors; 6 signals: R, G, B without filter and with Wratten absorption filter number 66; (original -> reproduction).

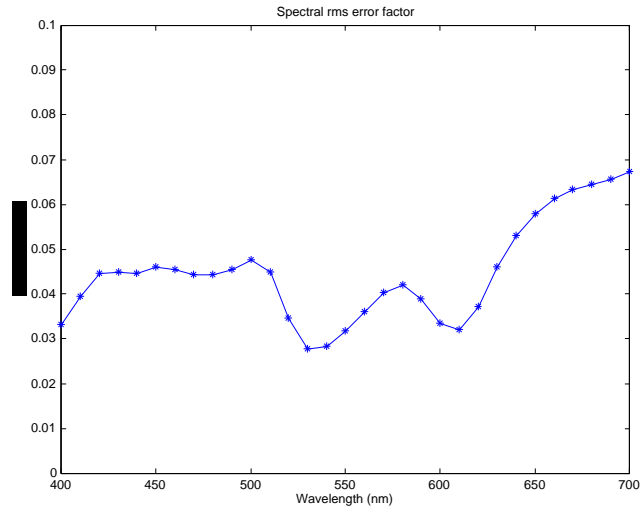


Figure 15. Spectral rms error for spectral reconstruction using 6 eigenvectors; 6 signals: R, G, B without filter and with Wratten absorption filter number 66.

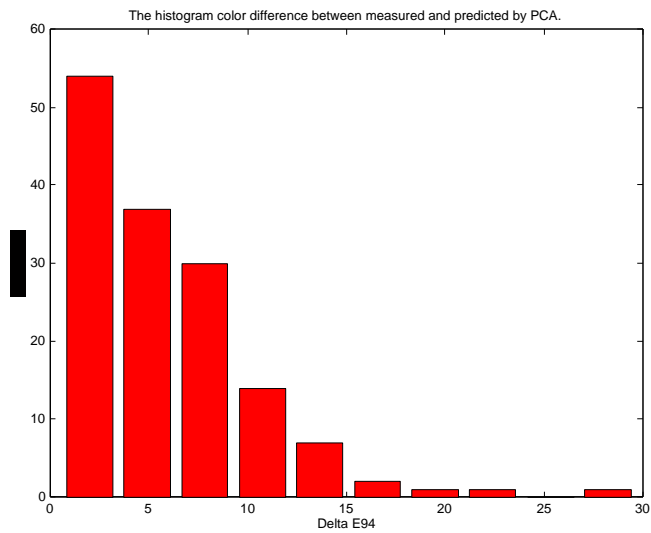


Figure 16. ΔE^*_{94} histogram for spectral reconstruction using 6 eigenvectors; 6 signals: R, G, B without filter and with Wratten absorption filter number 66.

Target III: set of 105 painted patches

I) Linear method using simulated digital counts (IBM DCS)

A set of 105 painted patches was imaged for various combinations of R, G, and B channels without filters and with filters (Kodak Wratten filters number 38 and 66 plus didymium filter). The results of the spectral reconstruction for 6 channels are summarized in tables VIII to XIII.

6 eigenvectors and channels (R, G, B without filter and with Wratten filter number 38)

Table VIII. Spectral reconstruction using 6 eigenvectors; 6 signals (R, G, B without filter and R, G, B with Wratten absorption filter number 38).

Patch	ΔE^*_{94}	reflectance rms error factor	Metameric Index
Average	0.84	0.019	0.39
Std Dev	0.47	0.006	0.26
Max	1.91	0.034	1.00
Min	0.09	0.006	0.01

The spectral reconstruction for every combination of filters produced quite accurate colorimetric results. Since the colorimetric accuracy graph for all the patches do not produce perceptible difference in a^* by b^* plot for different combination of filters, they were omitted in this report. As an example, Figure 17 shows the colorimetric accuracy for the spectral reconstruction using 6 eigenvectors, 6 channels (R, G, B without filter and with Wratten absorption filter number 38). Instead of representing the a^* by b^* plot, the results were presented in the form of E^*_{94} histograms. The spectral and colorimetric accuracy are sho

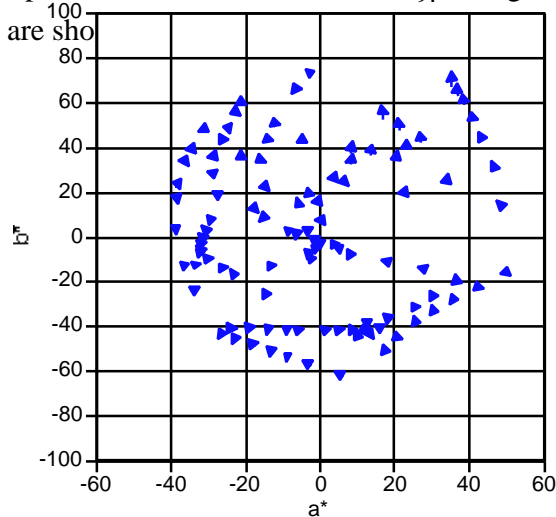


Figure 17. Colorimetric accuracy using 6 eigenvectors; 6 signals: R, G, B without filter and with Wratten absorption filter number 38; (original -> reproduction).

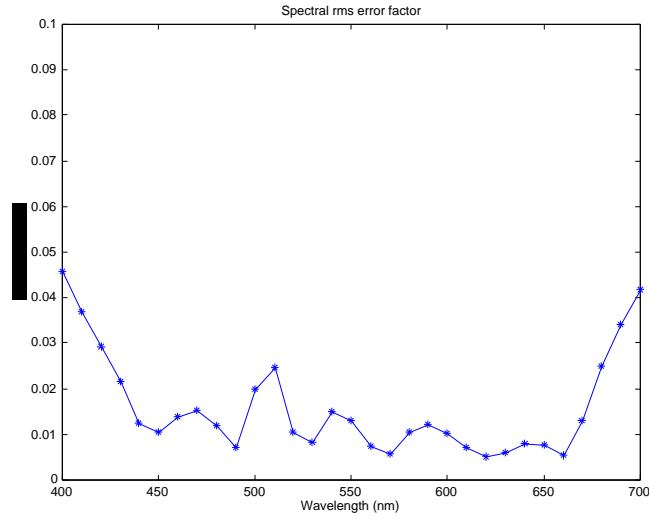


Figure 18. Spectral rms error for spectral reconstruction using 6 eigenvectors; 6 signals: R, G, B without filter and with Wratten absorption filter number 38.

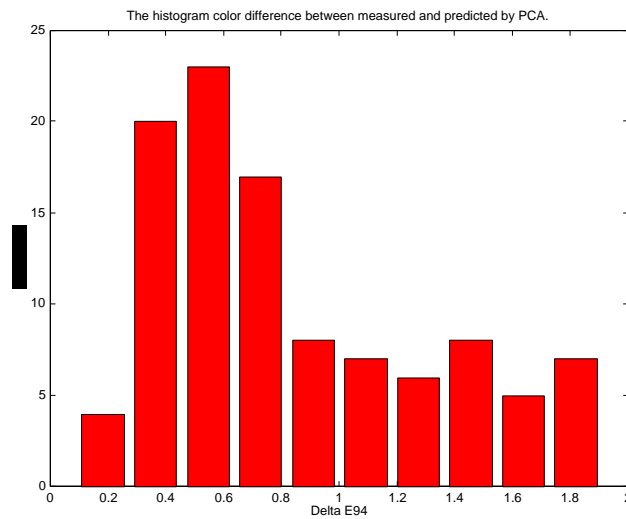


Figure 19. E^*_{94} histogram for spectral reconstruction using 6 eigenvectors; 6 signals: R, G, B without filter and with Wratten absorption filter number 38.

6 eigenvectors; 6 channels (R, G, B without filter and with Wratten filter number 66)

Table IX. Spectral reconstruction using 6 eigenvectors; 6 signals : R, G, B without filter and with Wratten absorption filter number 66.

Patch	ΔE^*_{94}	reflectance rms error factor	Metameric Index
Average	0.88	0.017	0.37
Std Dev	0.54	0.006	0.24
Max	2.39	0.030	1.42
Min	0.07	0.005	0.02

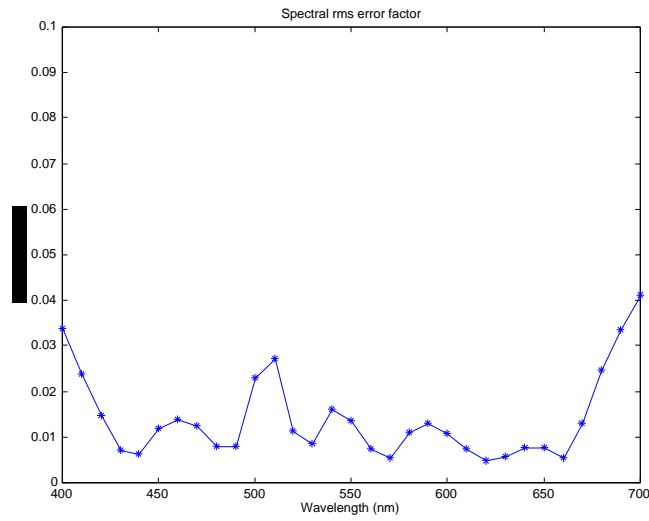


Figure 20. Spectral rms error for spectral reconstruction using 6 eigenvectors; 6 signals: R, G, B without filter and R, G, B with Wratten absorption filter number 66.

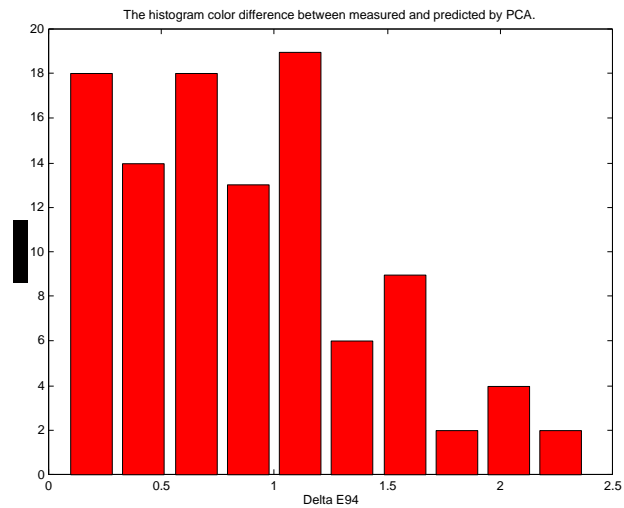


Figure 21. E^*_{94} histogram for spectral reconstruction using 6 eigenvectors; 6 signals: R, G, B without filter and R, G, B with Wratten absorption filter number 66.

6 eigenvectors; 6 channels (R, G, B without filter and with didymium filter)

Table X. Spectral reconstruction using 6 signals: R, G, B without filter and with didymium filter.

Patch	ΔE^*_{94}	reflectance rms error factor	Metameric Index
Average	1.07	0.017	0.72
Std Dev	0.59	0.006	0.56
Max	2.57	0.031	2.73
Min	0.12	0.005	0.03

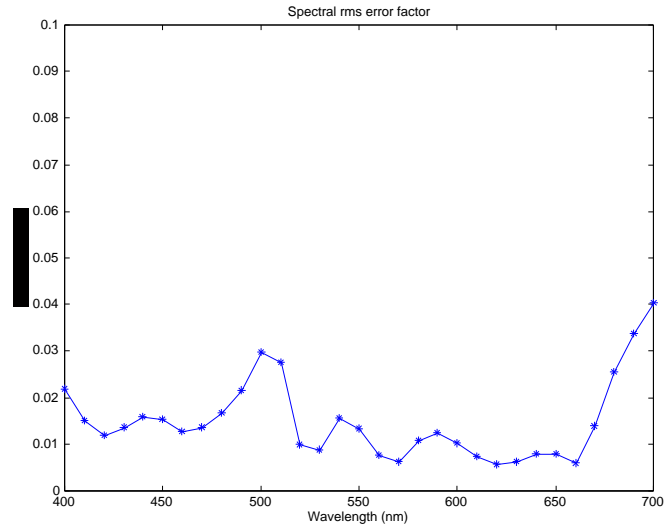


Figure 22. Spectral rms error for spectral reconstruction using 6 eigenvectors; 6 signals: R, G, B without filter and with didymium filter.

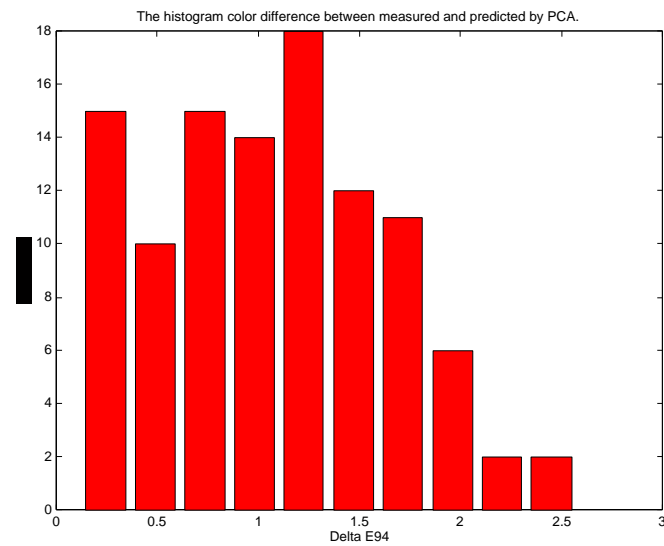


Figure 23. E^*_{94} histogram for spectral reconstruction using 6 eigenvectors; 6 signals: R, G, B without filter and with didymium filter.

6 channels (R, G, B with Wratten absorption filter number 38 and with didymium filter)

Table XI. Spectral reconstruction using 6 eigenvectors; 6 signals: R, G, B with Wratten absorption filter number 38 and with didymium filter.

Patch	ΔE^*_{94}	reflectance rms error factor	Metameric Index
Average	1.04	0.018	0.64
Std Dev	0.67	0.006	0.44

Max	2.65	0.031	1.75
Min	0.10	0.005	0.03

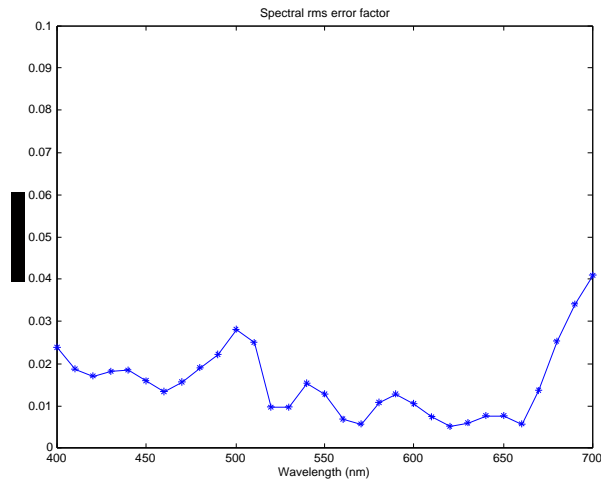


Figure 24. Spectral rms error for spectral reconstruction using 6 eigenvectors; 6 signals: R, G, B with Wratten absorption filter number 38 and with didymium filter.

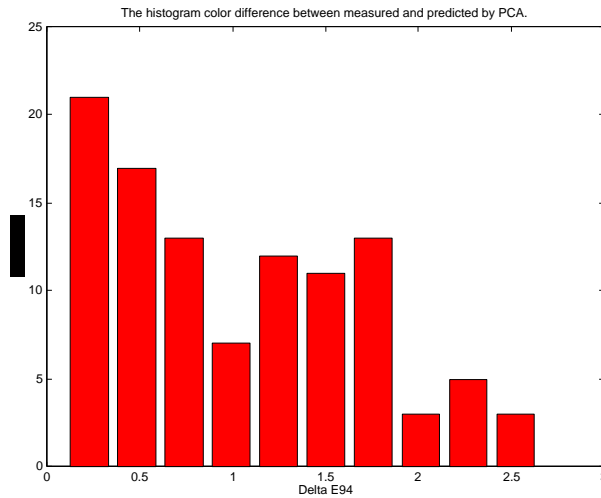


Figure 25. E^*_{94} histogram for spectral reconstruction using 6 eigenvectors; 6 signals: R, G, B with Wratten absorption filter number 38 and with didymium filter.

6 eigenvectors; 6 channels (R, G, B with Wratten absorption filters number 38 and 66)

Table XII. Spectral reconstruction using 6 eigenvectors; signals: R, G, B with Wratten absorption filters number 38 and 66.

Patch	ΔE^*_{94}	reflectance rms error factor	Metameric Index
Average	0.77	0.016	0.31

Std Dev	0.38	0.005	0.17
Max	2.01	0.029	0.82
Min	0.28	0.004	0.05

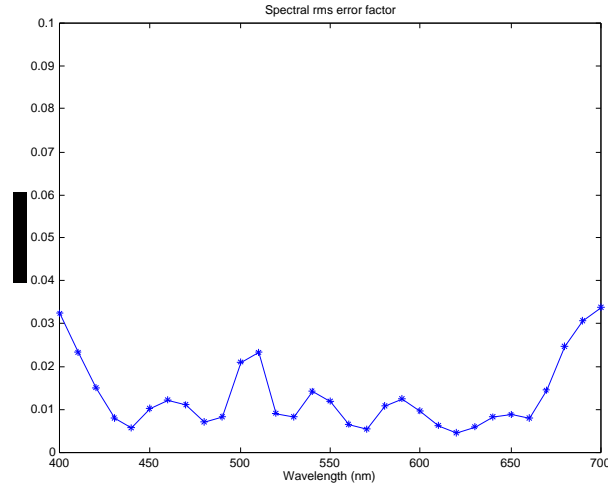


Figure 26. Spectral rms error for spectral reconstruction using 6 eigenvectors; 6 signals: R, G, B with Wratten absorption filters number 38 and 66.

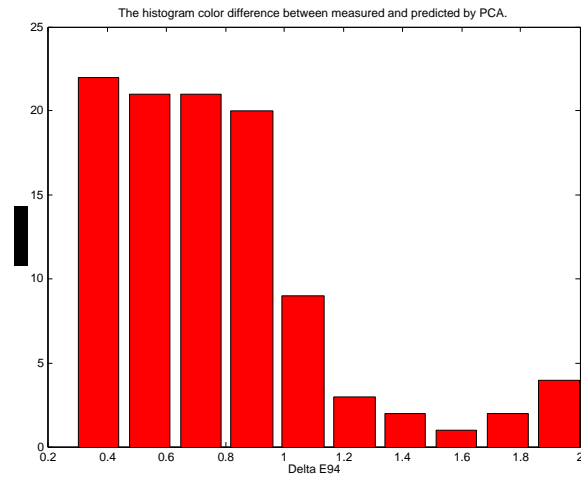


Figure 27. E^*_{94} histogram for spectral reconstruction using 6 eigenvectors; 6 signals: R, G, B with Wratten absorption filter2 number 38 and 66.

6 eigenvectors; 6 channels (R, G, B with Wratten absorption filter number 66 and with didymium filter)

Table XIII. Spectral reconstruction using 6 eigenvectors; 6 signals: R, G, B with Wratten absorption filter number 66 and with didymium filter).

Patch	ΔE^*_{94}	reflectance rms error factor	Metameric Index
Average	0.86	0.016	0.35

Std Dev	0.47	0.006	0.25
Max	2.12	0.029	1.49
Min	0.09	0.004	0.04

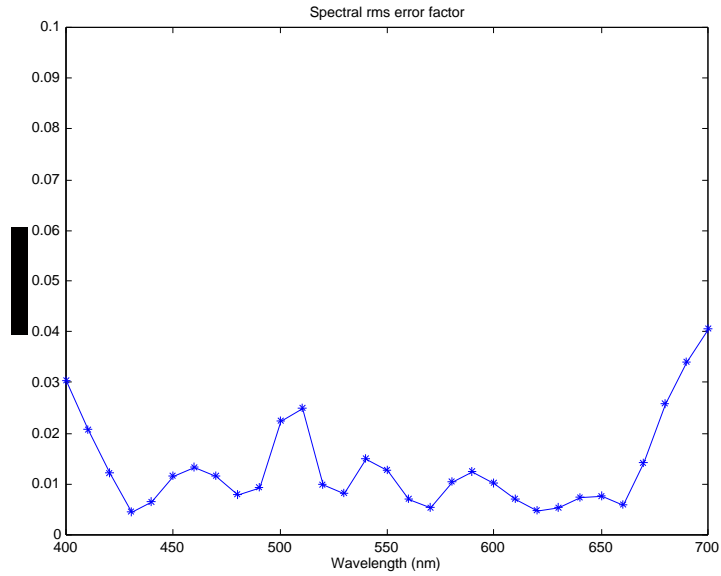


Figure 28. Spectral rms error for spectral reconstruction using 6 eigenvectors; 6 signals: R, G, B with Wratten absorption filter number 66 and with didymium filter.

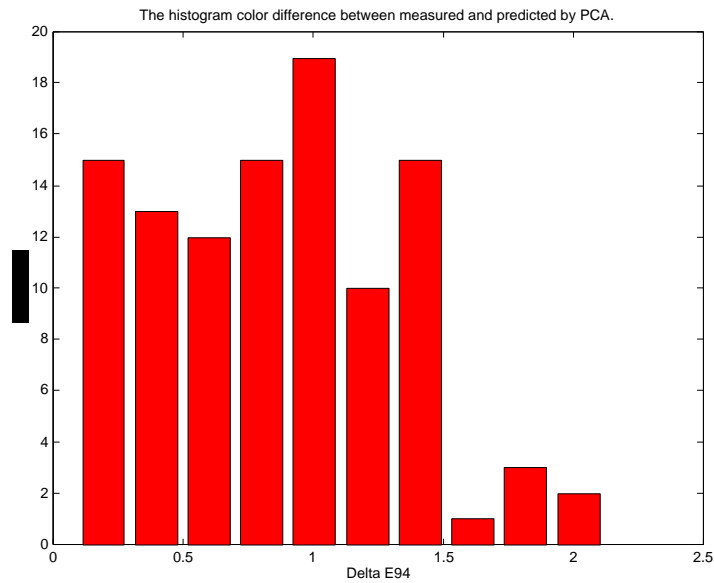


Figure 29. E^*_{94} histogram for spectral reconstruction using 6 eigenvectors; 6 signals: R, G, B with Wratten absorption filter number 66 and with didymium filter.

From Figures 17 to 29 and Tables VIII to XIII, it is possible to see that the best overall averaged colorimetric and spectral results are obtained for the spectral reconstruction using 6 eigenvectors and 6 signals from R, G, B without filter and R, G, B with light blue Wratten absorption filter number 66 that was the same result obtained using the other targets. However, in general, the results were worse than the results obtained for Macbeth ColorChecker.

II) Linear method using measured digital counts (IBM DCS)

This method was applied for 6 eigenvectors and 6 channels (R, G, B without filter and with Wratten filter number 38). The results are summarized in Table XIV and figures 30 to 32.

Table XIV. Spectral reconstruction using 6 eigenvectors; 6 signals (R, G, B without filter and R, G, B with Wratten absorption filter number 66).

Patch	ΔE^*_{94}	reflectance rms error factor	Metameric Index
Average	1.59	0.030	1.95
Std Dev	1.39	0.010	1.23
Max	12.15	0.054	5.70
Min	0.20	0.010	0.18

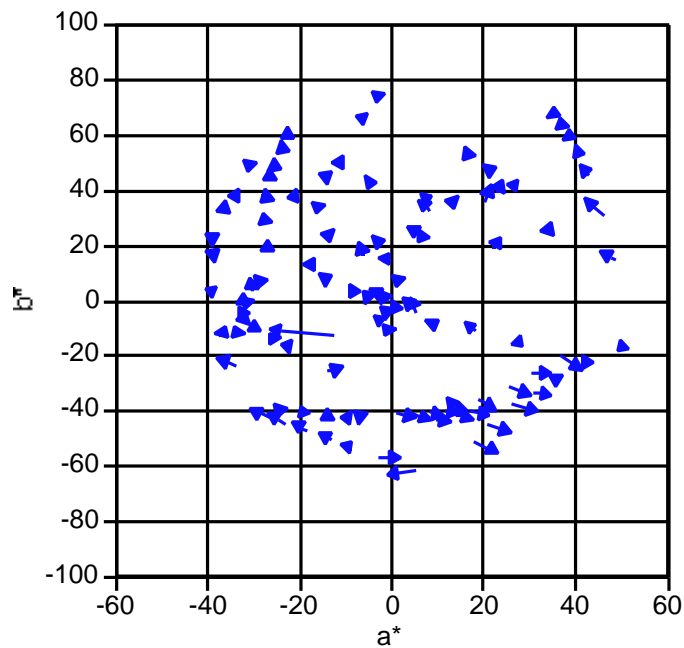


Figure 30. Colorimetric accuracy using 6 eigenvectors; 6 signals: R, G, B without filter and with Wratten absorption filter number 66; (original -> reproduction).

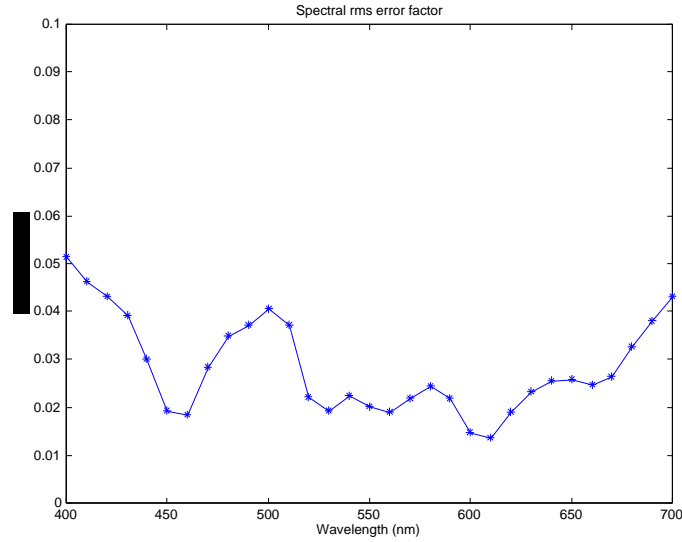


Figure 31. Spectral rms error for spectral reconstruction using 6 eigenvectors; 6 signals: R, G, B without filter and with Wratten absorption filter number 66.

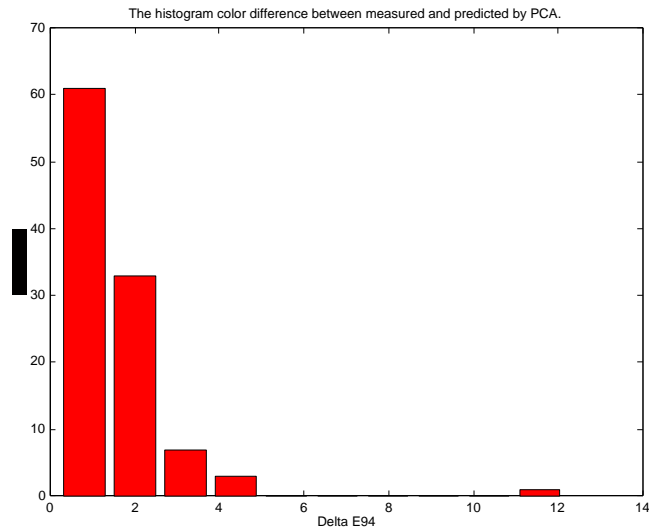


Figure 32. ΔE^*_{94} histogram for spectral reconstruction using 6 eigenvectors; 6 signals: R, G, B without filter and with Wratten absorption filter number 66.

From Table XIV and Figures 30 to 32 it is possible to see that the performance of the spectral reconstruction using measured digital counts instead of simulated ones was better for the set of 105 painted patches than the set of 147 painted patches.

From all the results above it is possible to conclude that the result of the spectral reconstruction in reflectance space is unacceptable using just 6 eigenvectors and 6 signals if we are using real digital counts instead of simulated ones. We need to change the dimensionality (from 6 to 9) or use some iterative method to improve the results.