

# Multi-spectral Image Acquisition and Spectral Reconstruction using a Trichromatic Digital Camera System associated with absorption filters

## PART VII Spectral reconstruction in the new empirical space

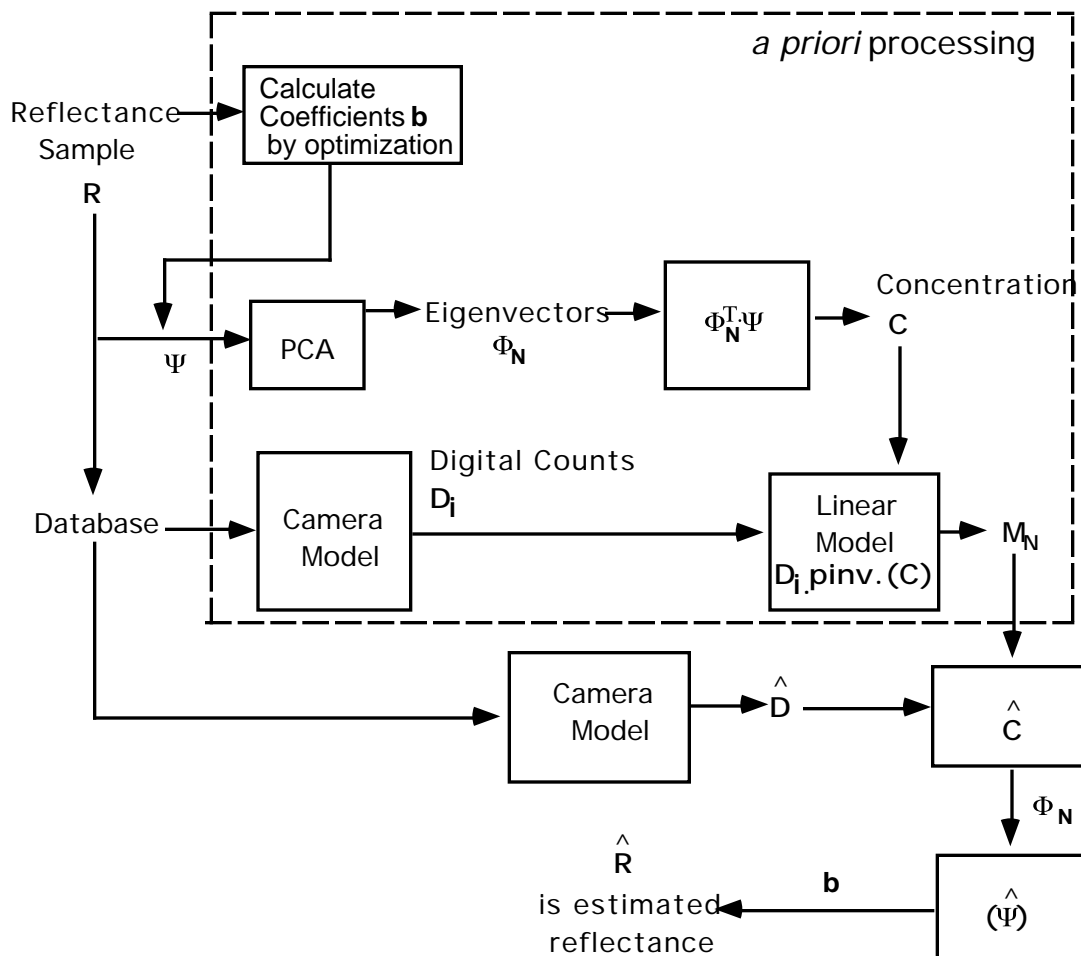
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### Abstract

This part describes some of the significant simulations performed to reconstruct the spectral reflectance of three targets, in the new empirical space using several combinations of filters and trichromatic signals. It also reports the colorimetric and spectral accuracy of the reconstructions, as well as the metameric index.

#### D) Linear method using simulated digital counts (IBM DCS)

The idea of the linear method using simulated digital counts is summarized in the flowchart of Figure 1.



**Figure 1.** Flowchart of the linear method in new empirical space.

At first, a camera model is built considering the spectral sensitivities of the digital camera, spectral power distribution of the illuminant, and the spectral transmittance of the filters used in the digitization. The spectral reflectances  $\mathbf{R}$  of the samples are measured and the matrix  $\Psi$  is calculated using equation (1). Then, principal component analysis is performed to calculate the eigenvectors  $\Phi_N$  of the K/S values. The concentration  $\mathbf{C}$  corresponding to the  $\Psi$  values is calculated. The camera model is used to obtain simulated digital counts from spectral reflectances  $\mathbf{R}$ . A transformation matrix  $\mathbf{M}_N$  from digital counts to concentration  $\mathbf{C}$  is computed.

$$\mathbf{b} = \mathbf{b} - \sqrt{\mathbf{R}}, \quad (1)$$

$$\mathbf{R} = (\mathbf{b} - \mathbf{b})^2, \quad (2)$$

where  $\mathbf{b}$  is an empirically determined offset vector.

The digital counts  $\hat{\mathbf{D}}$  of a subset  $\mathbf{R}'$  of the spectral reflectances is simulated using the camera model. The transformation matrix  $\mathbf{M}_N$ , calculated *a priori*, is used to predict the concentration corresponding to the digital counts  $\hat{\mathbf{D}}$ . Finally, the spectral reflectance  $\hat{\mathbf{R}}$  is predicted from  $\Psi$  values calculated using equation (2).

### Important consideration

At first, all the simulations were performed just normalizing the digital counts between zero and one. However, it produced very inaccurate results. The digital counts do not have direct proportionality with K/S space. In order to warrant that both digital counts and K/S values are in the same space, an empirical transformation for the digital counts, given by equation (3), was derived.

$$\mathbf{D}_c' = 1 - \sqrt{\mathbf{D}_c} \quad (3)$$

where  $\mathbf{D}_c'$  is the transformed digital count and  $\mathbf{D}_c$  is the normalized digital count.

### Target I: Macbeth ColorChecker

The digital counts of Macbeth ColorChecker were simulated by camera modeling, combining R, G, and B channels without filters, with Kodak Wratten filters number 38 and 66, and with didymium filter. The normalized digital counts were transformed according to equation (3). The results of the spectral reconstruction for 6 channels are summarized in Table I to VI and figures 2 to 14.

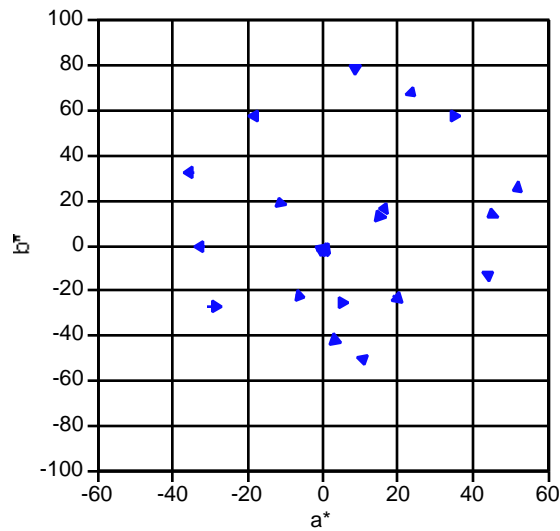
#### 6 eigenvectors and channels (R, G, B without filter and with Wratten filter number 38)

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

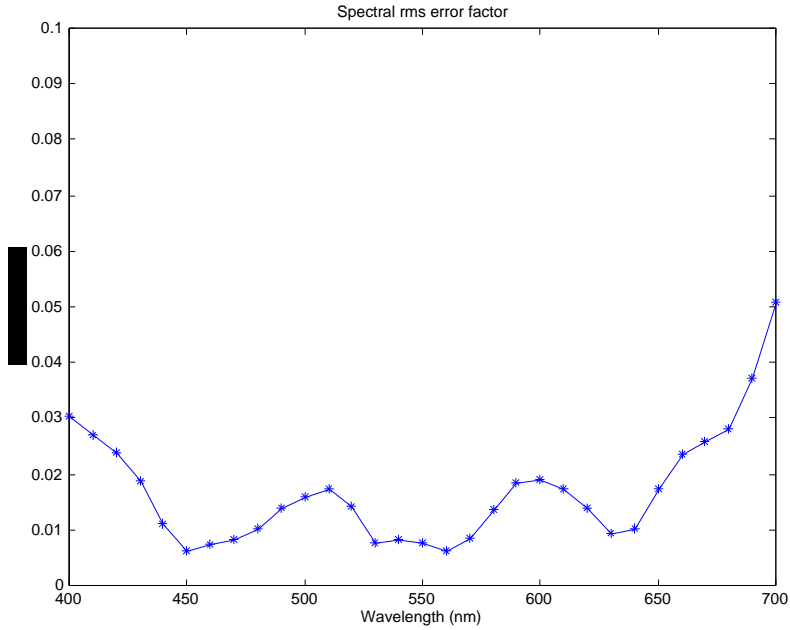
Patch	$\Delta E^*_{94}$	reflectance rms error factor	Metameric Index
Dark skin	0.81	0.010	0.47
Light skin	0.99	0.028	0.66
Blue sky	1.11	0.015	0.24
Foliage	0.79	0.013	0.72
Blue flower	0.80	0.013	0.07
Bluish green	0.90	0.016	0.44
Orange	0.50	0.025	0.50
Purplish red	0.69	0.015	0.61
Moderate red	0.82	0.028	0.42
Purple	1.16	0.043	1.01
Yellow green	0.81	0.011	0.16
Orange yellow	0.54	0.036	0.41
Blue	0.62	0.027	0.07
Green	1.28	0.010	0.16
Red	0.70	0.011	0.21
Yellow	0.80	0.015	0.07
Magenta	0.62	0.016	0.51
Cyan	2.35	0.013	0.41
White	0.60	0.018	0.05
Neutral 8	0.63	0.016	0.08
Neutral 6.5	0.88	0.016	0.18
Neutral 5	0.73	0.013	0.40
Neutral 3.5	0.74	0.009	0.54
Black	0.90	0.006	0.81
<b>Average</b>	<b>0.87</b>	<b>0.020</b>	<b>0.38</b>
<b>Std Dev</b>	<b>0.37</b>	<b>0.009</b>	<b>0.26</b>

<b>Max</b>	2.35	0.043	1.01
<b>Min</b>	0.50	0.006	0.05

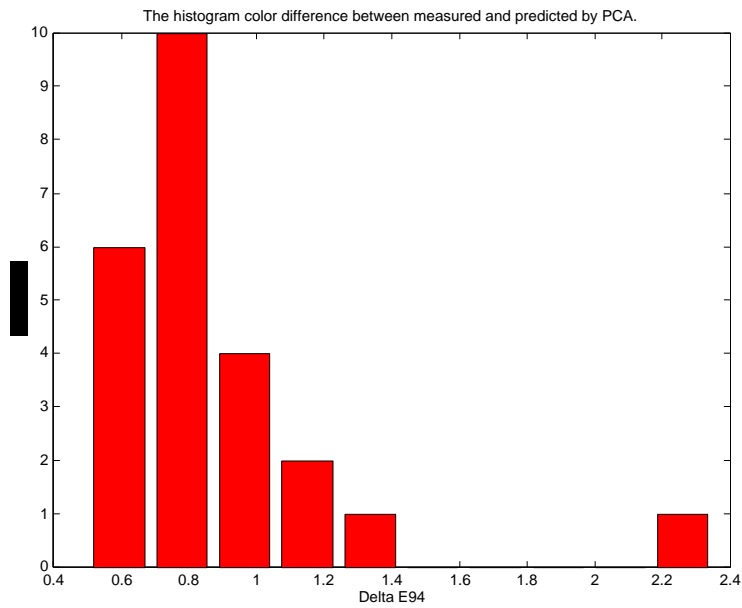
The spectral reconstruction for every combination of filters produced quite accurate colorimetric results. Since the colorimetric accuracy graph for all the patches do not produce perceptible difference in  $a^* \times b^*$  plot for different combination of filters, they were omitted in this report. 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 in Figures 3 to 14.



**Figure 2.** Colorimetric accuracy using 6 eigenvectors; 6 signals: R, G, B without filter and with Wratten absorption filter number 38; (original -> reproduction).



**Figure 3.** Spectral rms error for spectral reconstruction using 6 eigenvectors; 6 signals: R, G, B without filter and with Wratten absorption filter number 38.

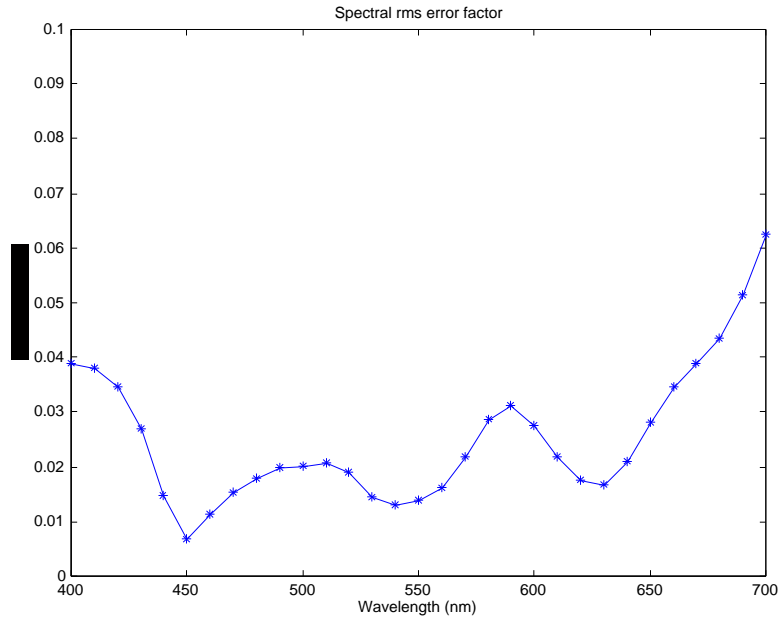


**Figure 4.**  $\Delta E^*_{94}$  histogram for spectral reconstruction using 6 eigenvectors; 6 signals: R, G, B without filter and with Wratten absorption filter number 38.

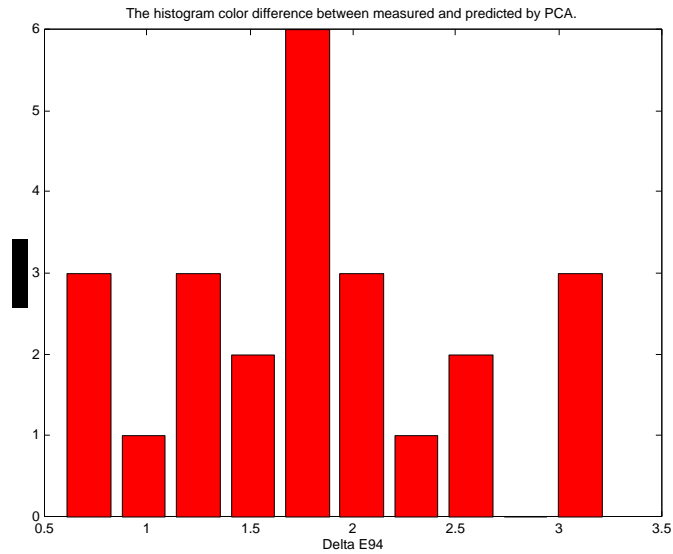
6 eigenvectors; 6 channels (R, G, B without filter and with Wratten filter number 66)

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

Patch	$\Delta E^*_{94}$	reflectance rms error factor	Metameric Index
Dark skin	1.74	0.015	0.68
Light skin	2.08	0.031	0.50
Blue sky	1.66	0.018	0.08
Foliage	1.73	0.014	0.53
Blue flower	2.08	0.021	0.21
Bluish green	1.58	0.015	0.34
Orange	1.26	0.052	1.40
Purplish red	1.63	0.020	1.33
Moderate red	0.76	0.036	0.79
Purple	2.08	0.066	0.82
Yellow green	1.83	0.021	0.43
Orange yellow	2.45	0.027	0.34
Blue	3.23	0.042	0.81
Green	1.86	0.012	0.30
Red	1.85	0.019	0.35
Yellow	1.01	0.024	0.51
Magenta	1.18	0.038	0.58
Cyan	3.03	0.021	0.33
White	0.58	0.025	0.54
Neutral 8	0.75	0.022	0.72
Neutral 6.5	1.12	0.022	0.90
Neutral 5	2.43	0.019	0.09
Neutral 3.5	2.59	0.013	0.97
Black	2.99	0.004	0.39
<b>Average</b>	<b>1.81</b>	<b>0.028</b>	<b>0.58</b>
<b>Std Dev</b>	<b>0.73</b>	<b>0.014</b>	<b>0.34</b>
<b>Max</b>	<b>3.23</b>	<b>0.066</b>	<b>1.40</b>
<b>Min</b>	<b>0.58</b>	<b>0.004</b>	<b>0.08</b>



**Figure 5.** 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.

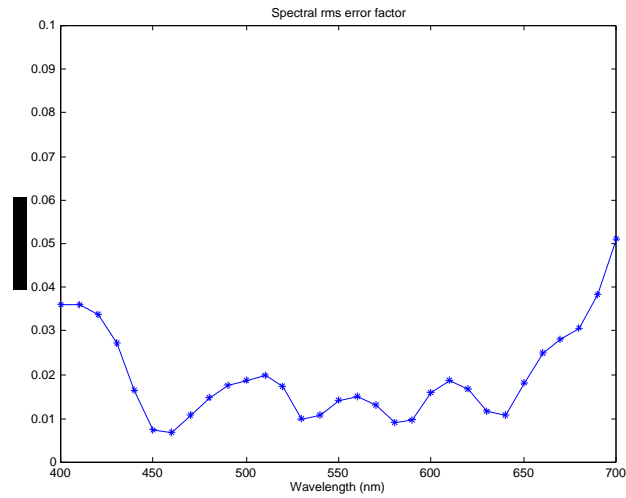


**Figure 6.**  $E^*_{94}$  histogram for spectral reconstruction using 6 eigenvectors; 6 signals: R, G, B without filter and R, G, B with Wratten absorption filter number 66.

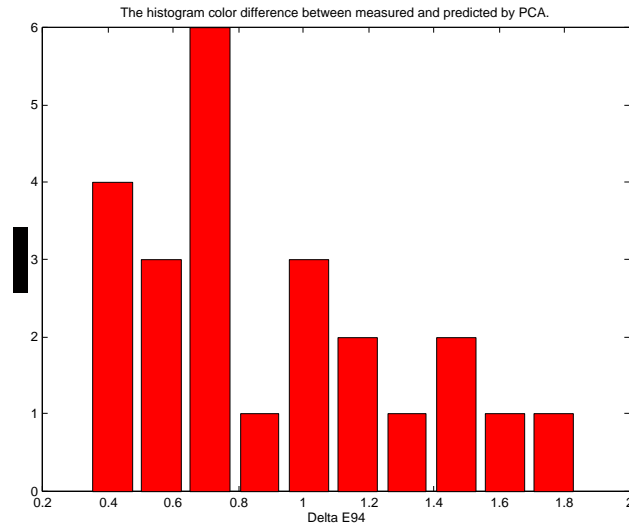
6 eigenvectors; 6 channels (R, G, B without filter and with didymium filter)

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

Patch	$\Delta E^*_{94}$	reflectance rms error factor	Metameric Index
Dark skin	1.04	0.007	0.60
Light skin	1.52	0.013	0.40
Blue sky	0.44	0.013	0.60
Foliage	1.09	0.015	1.23
Blue flower	0.34	0.017	0.35
Bluish green	0.58	0.014	0.40
Orange	1.05	0.025	0.54
Purplish red	1.12	0.015	0.66
Moderate red	0.64	0.037	0.95
Purple	1.84	0.055	1.89
Yellow green	0.66	0.016	0.25
Orange yellow	0.61	0.029	0.92
Blue	1.40	0.029	0.82
Green	1.27	0.012	0.53
Red	0.42	0.018	0.58
Yellow	0.69	0.020	0.24
Magenta	0.77	0.021	0.67
Cyan	1.62	0.035	1.17
White	0.39	0.018	0.12
Neutral 8	0.51	0.017	0.08
Neutral 6.5	0.78	0.017	0.22
Neutral 5	0.70	0.012	0.36
Neutral 3.5	0.82	0.006	0.43
Black	1.17	0.003	0.64
<b>Average</b>	<b>0.89</b>	<b>0.022</b>	<b>0.61</b>
<b>Std Dev</b>	<b>0.42</b>	<b>0.011</b>	<b>0.41</b>
<b>Max</b>	<b>1.84</b>	<b>0.055</b>	<b>1.89</b>
<b>Min</b>	<b>0.34</b>	<b>0.003</b>	<b>0.08</b>



**Figure 7.** Spectral rms error for spectral reconstruction using 6 eigenvectors; 6 signals: R, G, B without filter and with didymium filter.



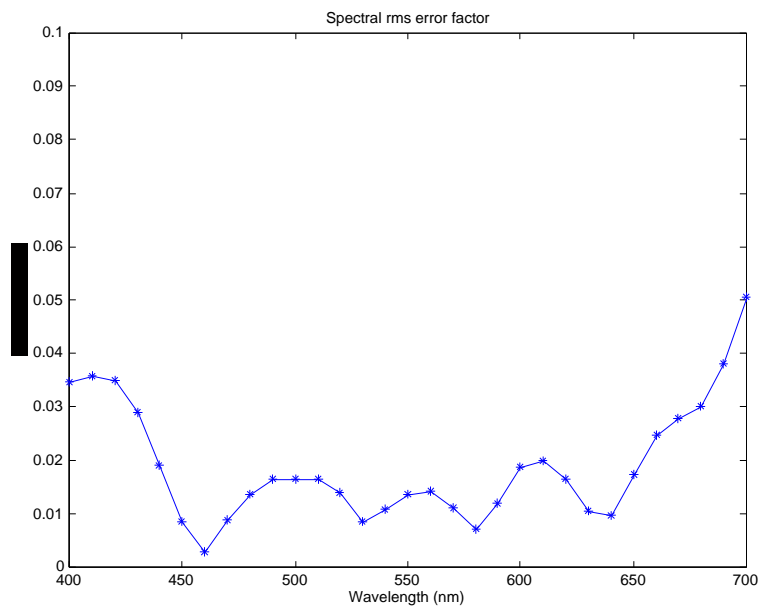
**Figure 8.**  $E^*_{94}$  histogram for spectral reconstruction using 6 eigenvectors; 6 signals: R, G, B without filter and with didymium filter.

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

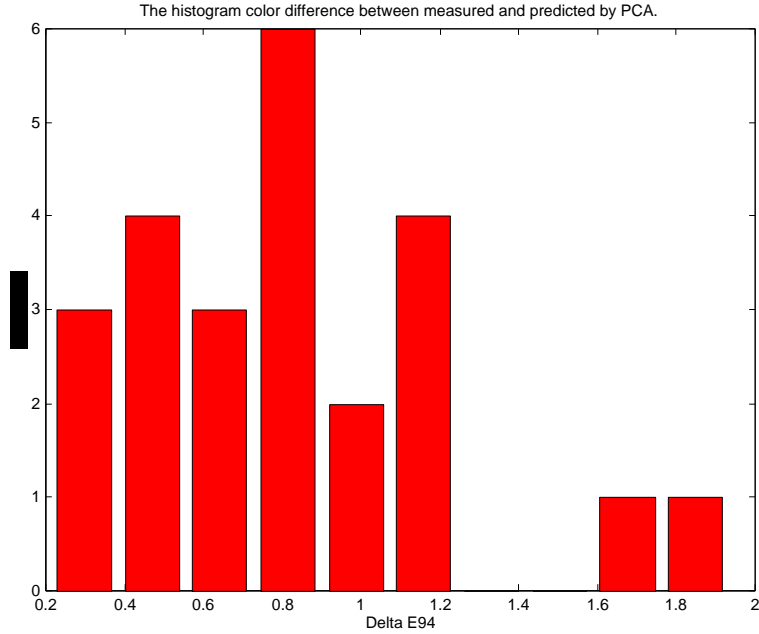
**Table IV.** Spectral reconstruction using 6 eigenvectors; 6 signals: R, G, B with Wratten absorption filter number 38 and with didymium filter.

Patch	$\Delta E^*_{94}$	reflectance rms error factor	Metameric Index
Dark skin	0.80	0.009	0.54
Light skin	0.98	0.017	0.49
Blue sky	1.18	0.013	0.18
Foliage	0.43	0.013	0.70
Blue flower	0.21	0.014	0.18
Bluish green	0.36	0.013	0.41
Orange	0.96	0.025	0.66
Purplish red	0.79	0.015	0.57
Moderate red	1.07	0.038	0.83
Purple	1.93	0.051	1.89
Yellow green	0.51	0.014	0.35
Orange yellow	0.44	0.035	0.64
Blue	1.10	0.022	0.17
Green	0.58	0.010	0.13
Red	0.35	0.011	0.51
Yellow	0.38	0.016	0.17

Magenta	0.88	0.017	0.73
Cyan	1.72	0.040	1.42
White	0.56	0.018	0.13
Neutral 8	0.59	0.021	0.14
Neutral 6.5	0.73	0.020	0.04
Neutral 5	0.74	0.013	0.14
Neutral 3.5	0.84	0.007	0.24
Black	1.08	0.004	0.44
<b>Average</b>	<b>0.80</b>	<b>0.022</b>	<b>0.49</b>
<b>Std Dev</b>	<b>0.42</b>	<b>0.011</b>	<b>0.43</b>
<b>Max</b>	<b>1.93</b>	<b>0.051</b>	<b>1.89</b>
<b>Min</b>	<b>0.21</b>	<b>0.004</b>	<b>0.04</b>



**Figure 9.** Spectral rms error for spectral reconstruction using 6 eigenvectors; 6 signals: R, G, B with Wratten absorption filter number 38 and with didymium filter.



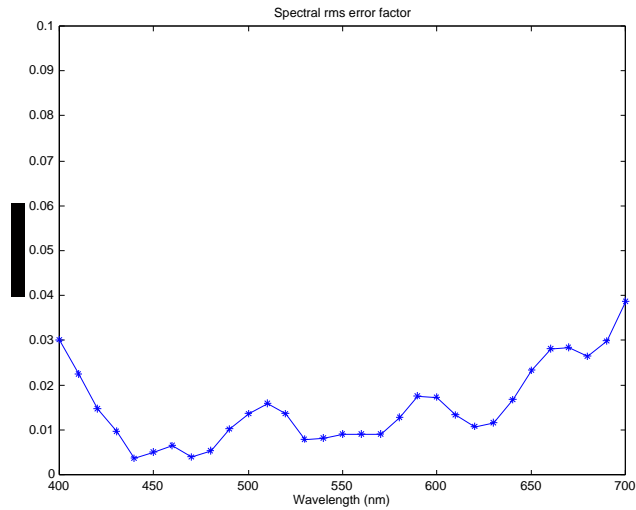
**Figure 10.**  $E^*_{94}$  histogram for spectral reconstruction using 6 eigenvectors; 6 signals: R, G, B with Wratten absorption filter number 38 and with didymium filter.

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

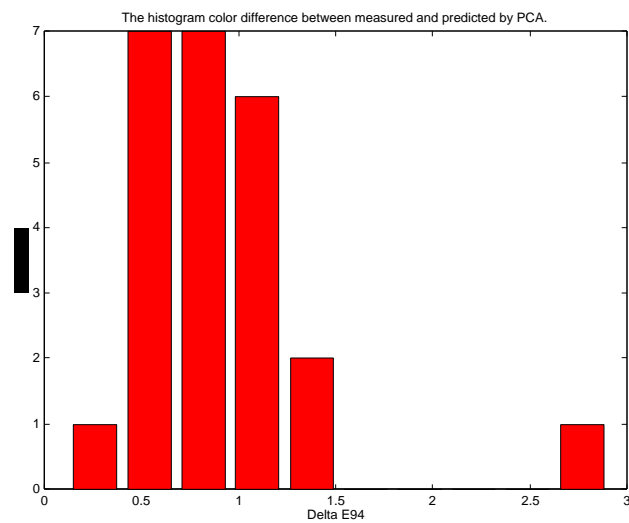
**Table V.** Spectral reconstruction using 6 eigenvectors; signals: R, G, B with Wratten absorption filters number 38 and 66.

Patch	$\Delta E^*_{94}$	reflectance rms error factor	Metameric Index
Dark skin	1.51	0.016	0.76
Light skin	1.78	0.016	0.49
Blue sky	2.39	0.025	1.58
Foliage	1.29	0.013	0.62
Blue flower	3.18	0.040	0.30
Bluish green	1.57	0.015	0.19
Orange	0.57	0.040	0.99
Purplish red	0.61	0.012	1.18
Moderate red	1.52	0.034	1.16
Purple	2.14	0.066	1.00
Yellow green	1.73	0.027	0.96
Orange yellow	1.59	0.029	0.89
Blue	3.29	0.036	1.82
Green	3.41	0.027	0.25
Red	3.48	0.036	1.97
Yellow	1.28	0.020	0.46
Magenta	1.92	0.030	1.49
Cyan	1.99	0.033	1.03
White	1.72	0.034	0.32

Neutral 8	0.60	0.015	0.11
Neutral 6.5	0.82	0.017	0.60
Neutral 5	1.42	0.017	0.39
Neutral 3.5	2.49	0.011	0.43
Black	2.89	0.005	0.15
<b>Average</b>	<b>1.88</b>	<b>0.029</b>	<b>0.80</b>
<b>Std Dev</b>	<b>0.88</b>	<b>0.013</b>	<b>0.53</b>
<b>Max</b>	<b>3.48</b>	<b>0.066</b>	<b>1.97</b>
<b>Min</b>	<b>0.57</b>	<b>0.005</b>	<b>0.11</b>



**Figure 11.** Spectral rms error for spectral reconstruction using 6 eigenvectors; 6 signals: R, G, B with Wratten absorption filters number 38 and 66.

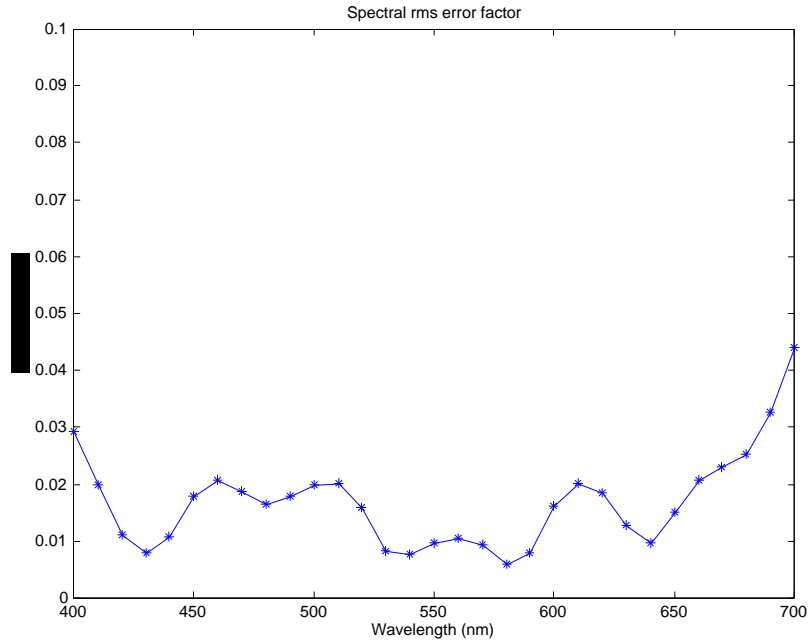


**Figure 12.**  $E^*_{94}$  histogram for spectral reconstruction using 6 eigenvectors; 6 signals: R, G, B with Wratten absorption filters number 38 and 66.

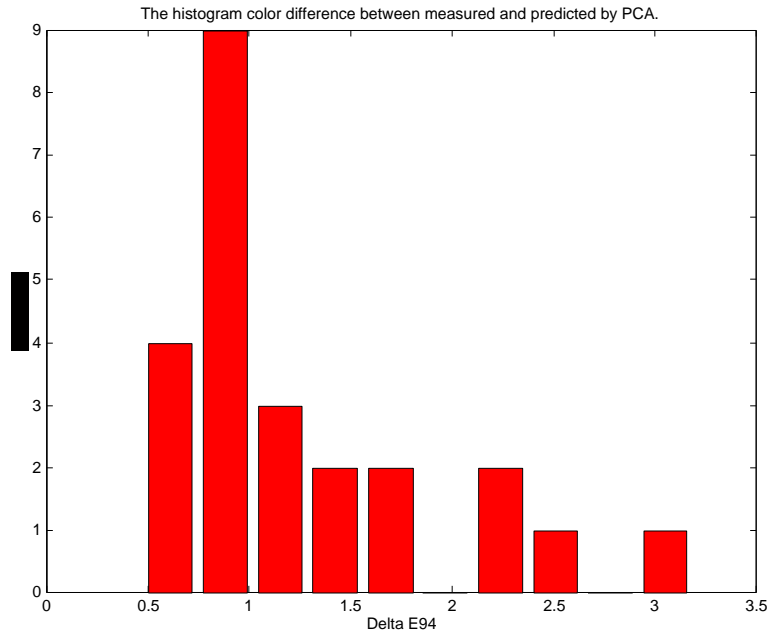
6 eigenvectors; 6 channels (R, G, B with Wratten absorption filter number 66 and with didymium filter)

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

Patch	$\Delta E^*_{94}$	reflectance rms error factor	Metameric Index
Dark skin	2.10	0.006	0.03
Light skin	2.46	0.015	0.26
Blue sky	0.84	0.012	0.38
Foliage	1.81	0.016	0.59
Blue flower	0.71	0.019	0.40
Bluish green	1.16	0.017	0.24
Orange	1.31	0.020	0.32
Purplish red	1.21	0.013	0.05
Moderate red	0.89	0.026	0.56
Purple	2.26	0.033	0.38
Yellow green	0.47	0.010	0.23
Orange yellow	1.01	0.022	0.41
Blue	1.64	0.024	0.76
Green	0.91	0.012	0.47
Red	3.19	0.020	0.73
Yellow	0.65	0.024	0.45
Magenta	1.14	0.018	0.51
Cyan	1.43	0.017	0.91
White	0.96	0.028	0.22
Neutral 8	0.92	0.023	0.32
Neutral 6.5	1.00	0.018	0.45
Neutral 5	0.78	0.013	0.44
Neutral 3.5	0.67	0.007	0.43
Black	0.98	0.004	0.46
<b>Average</b>	<b>1.27</b>	<b>0.019</b>	<b>0.42</b>
<b>Std Dev</b>	<b>0.66</b>	<b>0.007</b>	<b>0.20</b>
<b>Max</b>	<b>3.19</b>	<b>0.033</b>	<b>0.91</b>
<b>Min</b>	<b>0.47</b>	<b>0.004</b>	<b>0.03</b>



**Figure 13.** 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 14.**  $E^*_{94}$  histogram for spectral reconstruction using 6 eigenvectors; 6 signals: R, G, B with Wratten absorption filter number 66 and with didymium filter.

Observing the results of tables I to VI and figures 2 to 14, it is possible to see that the combination of trichromatic signals that produced the best colorimetric performance was using trichromatic signals of the image capture with light blue and didymium filter. In general, the bluish color patches, such as blue, blue sky, purple, and cyan presented the largest color differences. The spectral reconstruction using a pair of trichromatic values with very light green, light blue filters and with very light green and didymium filters did not present a good performance, probably because the low digital counts resulting from the simulations using these combinations.

### **Target II: Set of 147 painted patches**

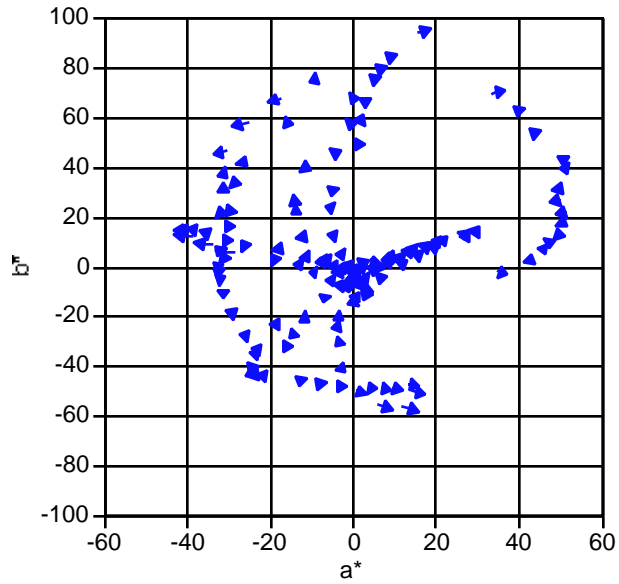
The digital counts of a set of 147 painted patches were simulated by camera modeling, combining R, G, and B channels without filters, with Kodak Wratten filters number 38 and 66, and with didymium filter. The normalized digital counts were transformed according to equation (3). The results of the spectral reconstruction for 6 channels are summarized in Table VII to XII and figures 15 to 27.

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

**Table VII** Spectral reconstruction using 6 signals: R, G, B without filter and with Wratten absorption filter number 38.

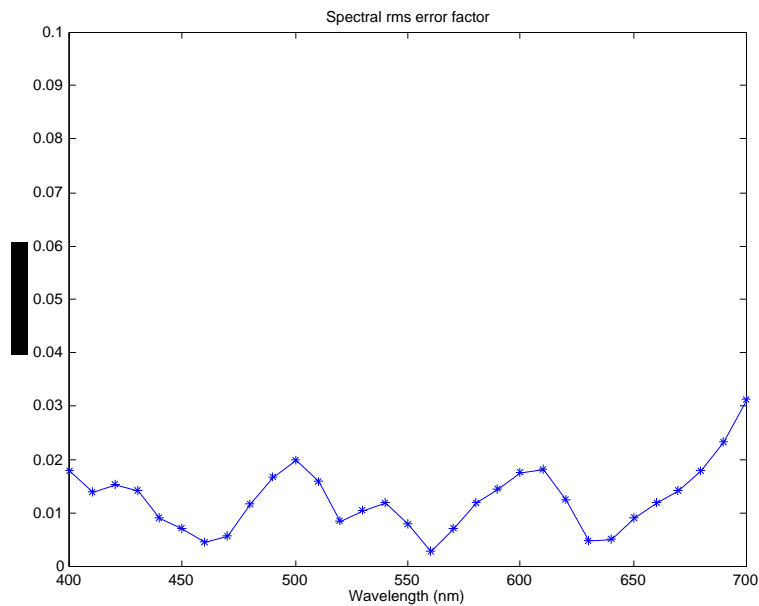
Patch	$\Delta E^*_{94}$	reflectance rms error factor	Metameric Index
<b>Average</b>	0.76	0.014	0.37
<b>Std Dev</b>	0.40	0.008	0.31
<b>Max</b>	2.58	0.040	1.70
<b>Min</b>	0.11	0.001	0.01

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 15 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 in Figures 16 to 27.

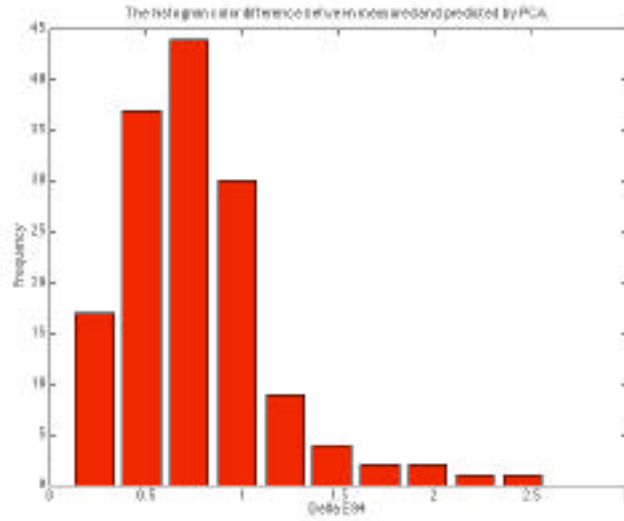


**Figure 15.** Colorimetric accuracy using 6 eigenvectors; 6 signals: R, G, B without filter and with Wratten absorption filter number 38; (original -> reproduction).

Figure 16 and Figure 17 show, respectively, the spectral rms error factor, and the  $E^*_{94}$  histogram for the spectral reconstruction using 6 eigenvectors; 6 signals: R, G, B without filter and with Wratten absorption filter number 38.



**Figure 16.** Spectral rms error for spectral reconstruction using 6 eigenvectors; 6 signals: R, G, B without filter and with Wratten absorption filter number 38.

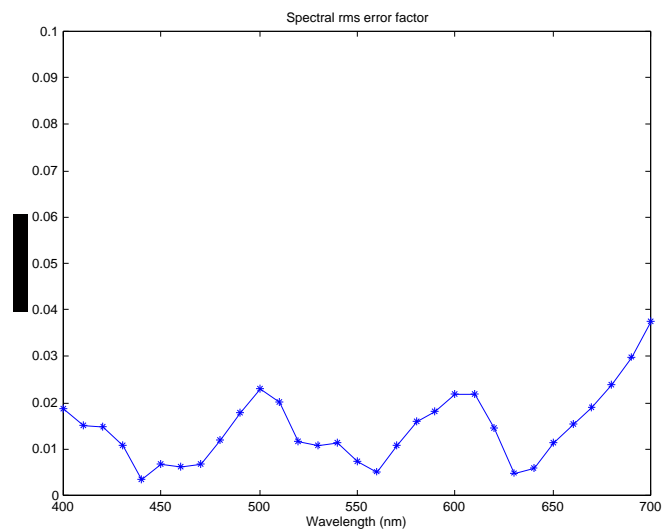


**Figure 17.**  $E^*_{94}$  histogram for spectral reconstruction using 6 eigenvectors; 6 signals: R, G, B without filter and with Wratten absorption filter number 38.

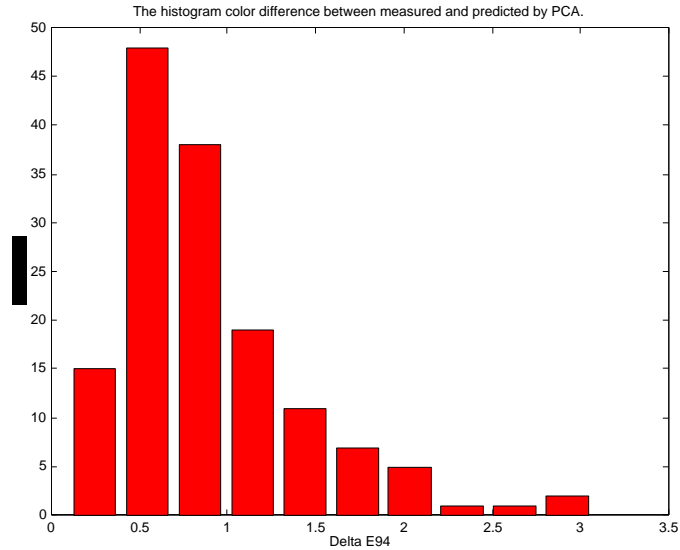
6 eigenvectors; 6 channels (R, G, B without filter and with Wratten filter number 66)

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

Patch	$\Delta E^*_{94}$	reflectance rms error factor	Metameric Index
<b>Average</b>	0.89	0.016	0.33
<b>Std Dev</b>	0.53	0.011	0.23
<b>Max</b>	3.07	0.054	0.96
<b>Min</b>	0.10	0.001	0.02



**Figure 18.** 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.

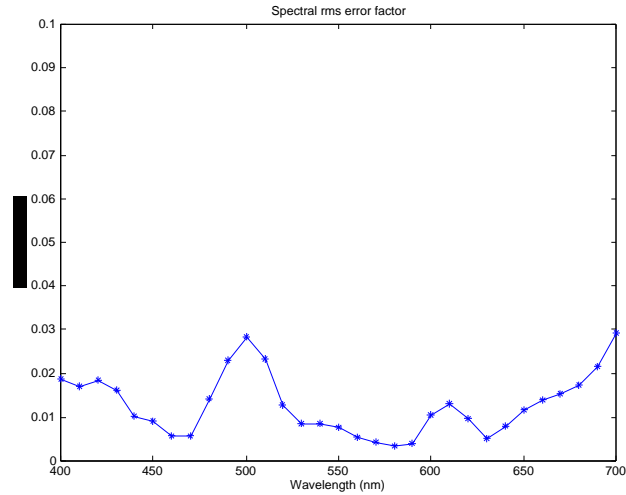


**Figure 19.**  $E^*_{94}$  histogram for spectral reconstruction using 6 eigenvectors; 6 signals: R, G, B without filter and R, G, B with Wratten absorption filter number 66.

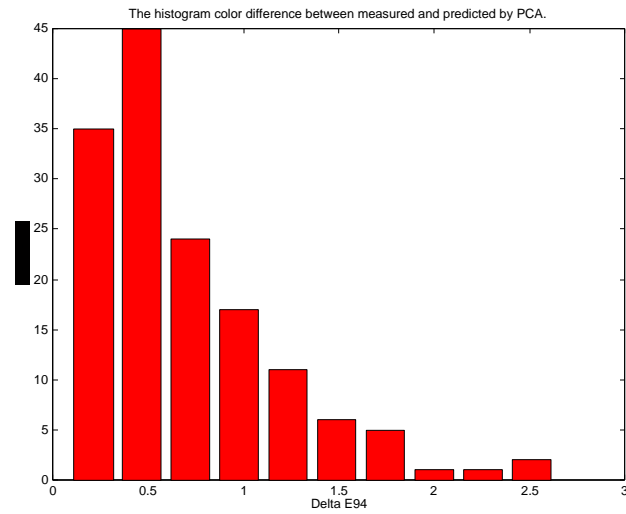
6 eigenvectors; 6 channels (R, G, B without filter and with didymium filter)

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

Patch	$\Delta E^*_{94}$	reflectance rms error factor	Metameric Index
<b>Average</b>	0.70	0.015	0.59
<b>Std Dev</b>	0.49	0.009	0.61
<b>Max</b>	2.64	0.043	2.98
<b>Min</b>	0.08	0.001	0.02



**Figure 20.** Spectral rms error for spectral reconstruction using 6 eigenvectors; 6 signals: R, G, B without filter and with didymium filter.

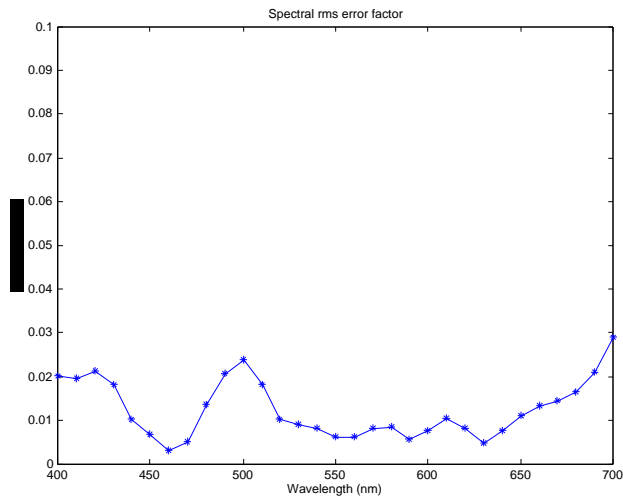


**Figure 21.**  $E^*_{94}$  histogram for spectral reconstruction using 6 eigenvectors; 6 signals: R, G, B without filter and with didymium filter.

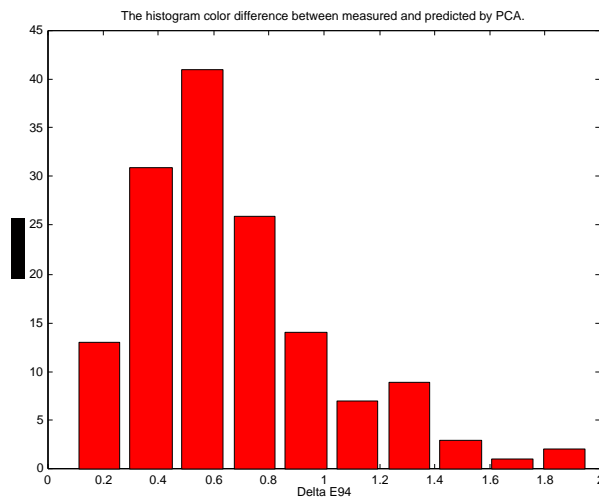
6 eigenvectors; 6 channels (R, G, B with Wratten absorption filters number 38 and with didymium filter)

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

Patch	$\Delta E^*_{94}$	reflectance rms error factor	Metameric Index
<b>Average</b>	0.67	0.014	0.39
<b>Std Dev</b>	0.35	0.008	0.36
<b>Max</b>	1.96	0.038	2.06
<b>Min</b>	0.09	0.001	0.03



**Figure 22.** Spectral rms error for spectral reconstruction using 6 eigenvectors; 6 signals: R, G, B with Wratten absorption filter number 38 and with didymium filter.

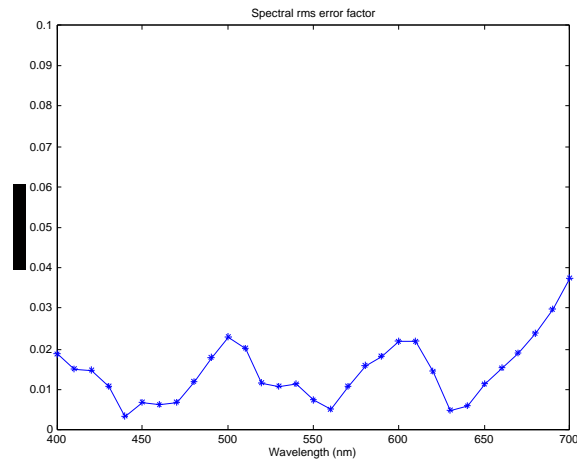


**Figure 23.**  $E^*_{94}$  histogram for spectral reconstruction using 6 eigenvectors; 6 signals: R, G, B with Wratten absorption filter number 38 and with didymium filter.

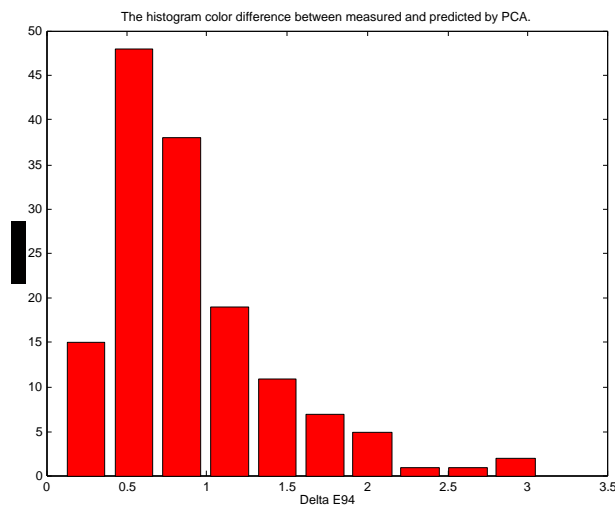
6 eigenvectors; 6 channels (R, G, B with Wratten absorption filters number 38 and 66)

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

Patch	$\Delta E^*_{94}$	reflectance rms error factor	Metameric Index
<b>Average</b>	0.89	0.016	0.33
<b>Std Dev</b>	0.53	0.011	0.23
<b>Max</b>	3.07	0.054	0.96
<b>Min</b>	0.10	0.001	0.02



**Figure 24.** Spectral rms error for spectral reconstruction using 6 eigenvectors; 6 signals: R, G, B with Wratten absorption filters number 38 and 66.



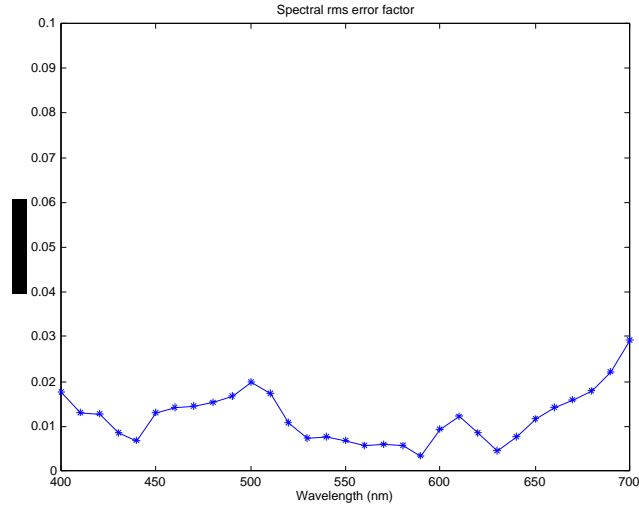
**Figure 24.**  $E^*_{94}$  histogram for spectral reconstruction using 6 eigenvectors; 6 signals: R, G, B with Wratten absorption filter number 38 and with Wratten absorption filter number 66.

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

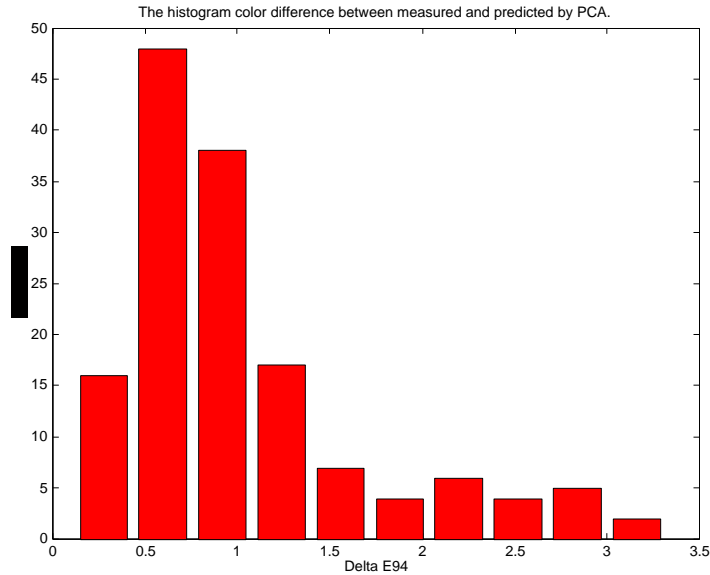
**Table XII.** Spectral reconstruction using 6 eigenvectors; 6 signals: R, G, B with Wratten absorption filter number 66 and with didymium filter).

Patch	$\Delta E^*_{94}$	reflectance rms error factor	Metameric Index
<b>Average</b>	<b>1.03</b>	<b>0.013</b>	<b>0.26</b>

<b>Std Dev</b>	0.67	0.008	0.23
<b>Max</b>	3.32	0.039	1.23
<b>Min</b>	0.11	0.001	0.03



**Figure 26.** 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 27.**  $E^*_{94}$  histogram for spectral reconstruction using 6 eigenvectors; 6 signals: R, G, B with Wratten absorption filter number 66 and with didymium filter.

Observing the results of tables VII to XII and figures 15 to 27, it is possible to see that the combination of trichromatic signals that produced the best colorimetric and spectral performance was using trichromatic signals of the image captured with light blue and didymium filters. However, any combination of trichromatic signals produced reasonable

results, with mean  $E^*_{94}$  less than a unity (except the signals obtained combining didymium and very light green filters), spectral reflectance rms error equal or less than 2%, and metamerism index less than a unity.

**Target III: Set of 105 painted patches**

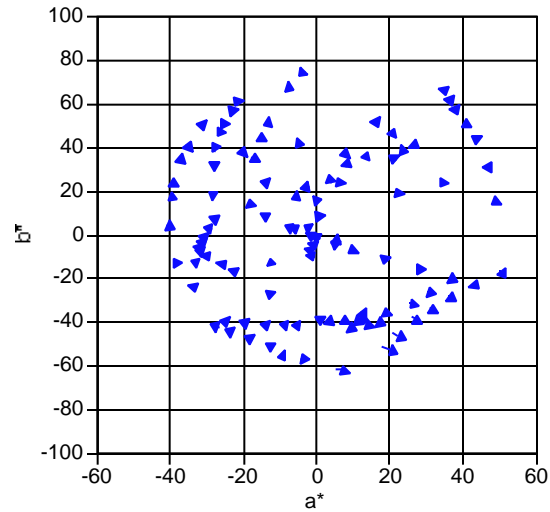
The digital counts of a set of 105 painted patches were simulated by camera modeling, combining R, G, and B channels without filters, with Kodak Wratten filters number 38 and 66, and with didymium filter. The normalized digital counts were transformed according to equation (3). The results of the spectral reconstruction for 6 channels are summarized in Table XIII to XVIII and figures 28 to 40.

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

**Table XIII** Spectral reconstruction using 6 signals: R, G, B without filter and with Wratten absorption filter number 38.

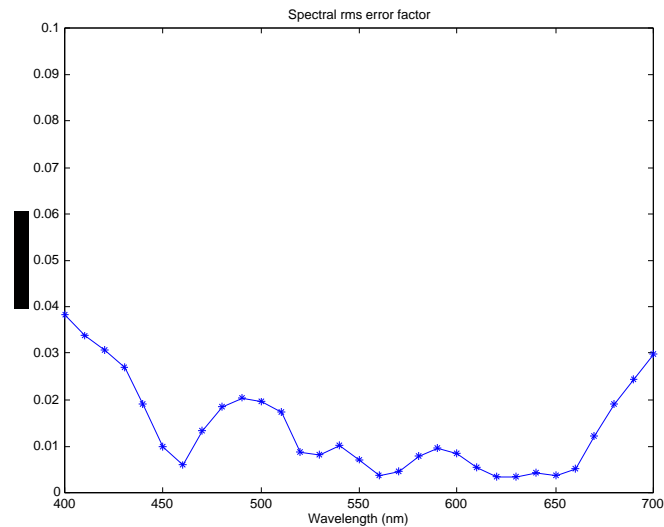
Patch	$\Delta E^*_{94}$	reflectance rms error factor	Metameric Index
<b>Average</b>	0.59	0.017	0.57
<b>Std Dev</b>	0.35	0.008	0.31
<b>Max</b>	1.81	0.040	1.65
<b>Min</b>	0.11	0.005	0.03

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 28 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 in Figures 29 to 40.

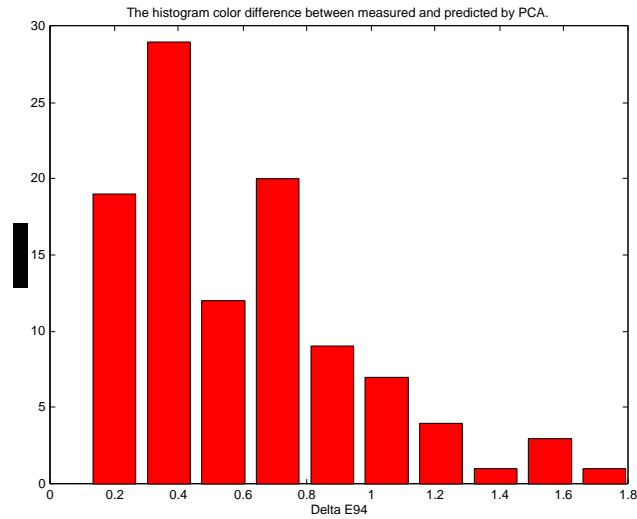


**Figure 28.** Colorimetric accuracy using 6 eigenvectors; 6 signals: R, G, B without filter and with Wratten absorption filter number 38; (original -> reproduction).

Figure 29 and Figure 16 show, respectively, the spectral rms error factor, and the  $E^*_{94}$  histogram for the spectral reconstruction using 6 eigenvectors; 6 signals: R, G, B without filter and with Wratten absorption filter number 38.



**Figure 29.** Spectral rms error for spectral reconstruction using 6 eigenvectors; 6 signals: R, G, B without filter and with Wratten absorption filter number 38.

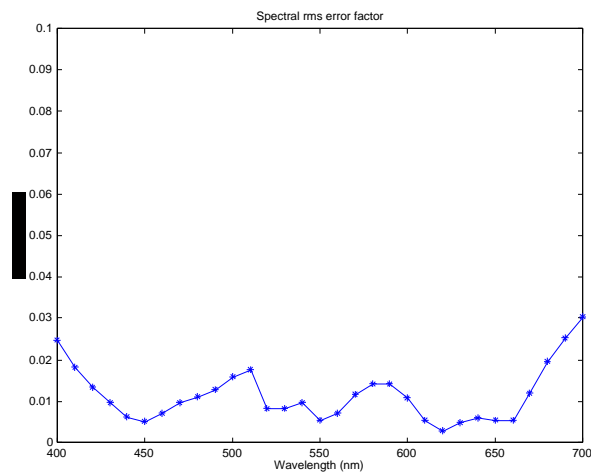


**Figure 30.**  $E^*_{94}$  histogram for spectral reconstruction using 6 eigenvectors; 6 signals: R, G, B without filter and with Wratten absorption filter number 38.

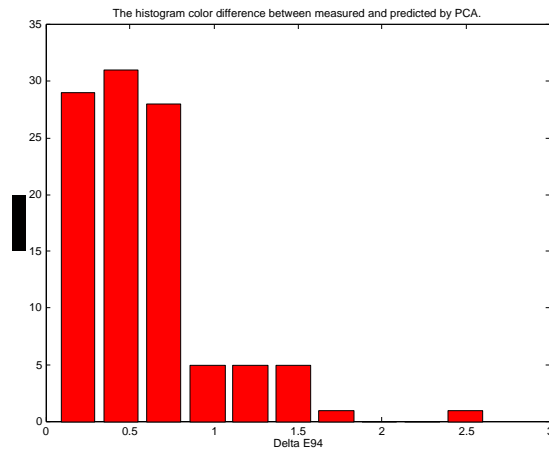
6 eigenvectors; 6 channels (R, G, B without filter and with Wratten filter number 66)

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

Patch	$\Delta E^*_{94}$	reflectance rms error factor	Metameric Index
<b>Average</b>	0.59	0.013	0.23
<b>Std Dev</b>	0.42	0.005	0.14
<b>Max</b>	2.62	0.038	0.76
<b>Min</b>	0.06	0.005	0.00



**Figure 31.** 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.

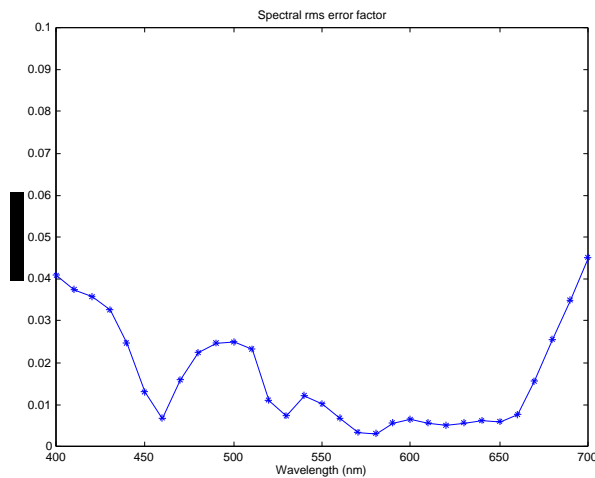


**Figure 32.**  $E^*_{94}$  histogram for spectral reconstruction using 6 eigenvectors; 6 signals: R, G, B without filter and R, G, B with Wratten absorption filter number 66.

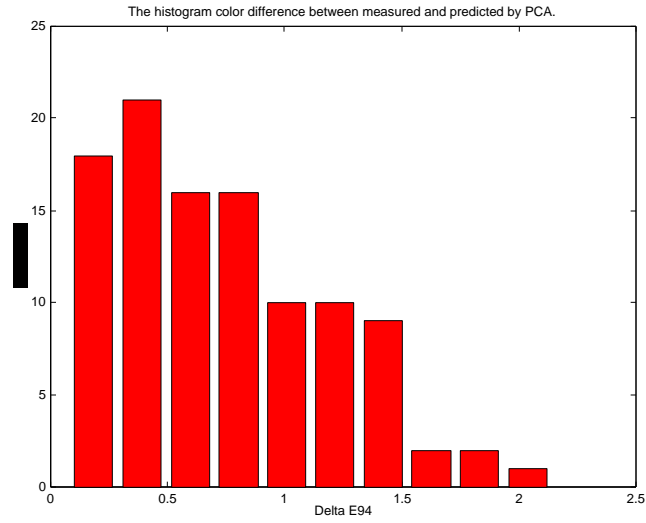
6 eigenvectors; 6 channels (R, G, B without filter and with didymium filter)

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

Patch	$\Delta E^*_{94}$	reflectance rms error factor	Metameric Index
<b>Average</b>	0.73	0.021	0.95
<b>Std Dev</b>	0.45	0.010	0.51
<b>Max</b>	2.14	0.046	2.27
<b>Min</b>	0.08	0.006	0.06



**Figure 33.** Spectral rms error for spectral reconstruction using 6 eigenvectors; 6 signals: R, G, B without filter and with didymium filter.

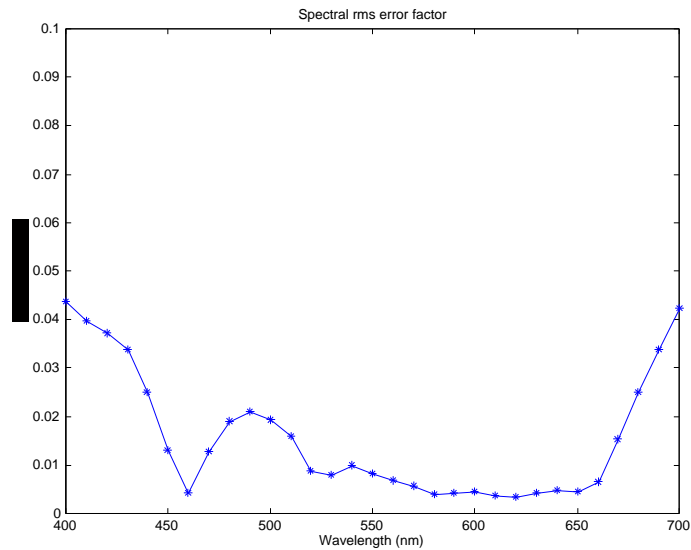


**Figure 34.**  $E^*_{94}$  histogram for spectral reconstruction using 6 eigenvectors; 6 signals: R, G, B without filter and with didymium filter.

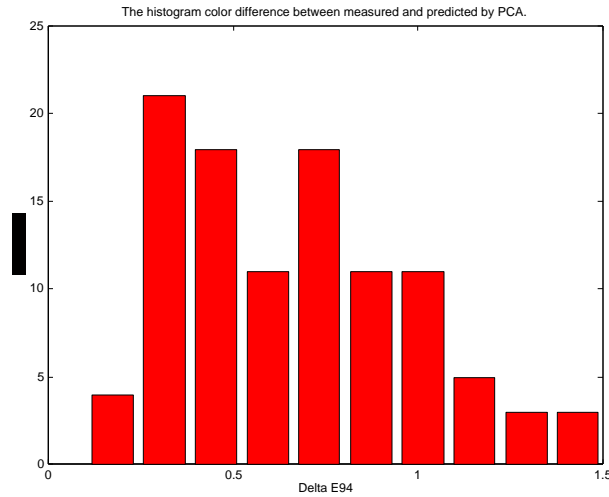
6 channels (R, G, B with Wratten absorption filter number 38 and with didymium filter)

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

Patch	$\Delta E^*_{94}$	reflectance rms error factor	Metameric Index
<b>Average</b>	0.67	0.020	0.68
<b>Std Dev</b>	0.31	0.010	0.41
<b>Max</b>	1.50	0.046	1.78
<b>Min</b>	0.10	0.006	0.04



**Figure 35.** Spectral rms error for spectral reconstruction using 6 eigenvectors; 6 signals: R, G, B with Wratten absorption filter number 38 and with didymium filter.

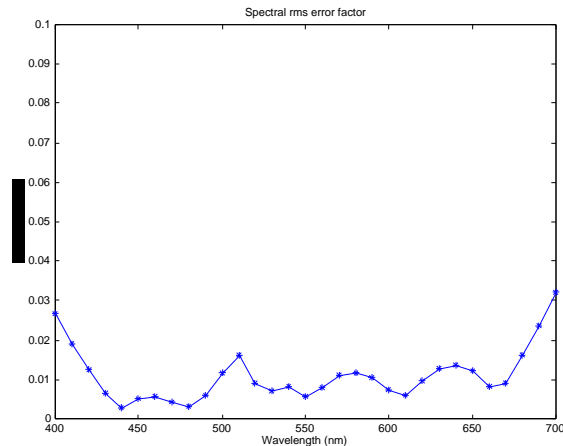


**Figure 36.**  $E^*_{94}$  histogram for spectral reconstruction using 6 eigenvectors; 6 signals: R, G, B with Wratten absorption filter number 38 and with didymium filter.

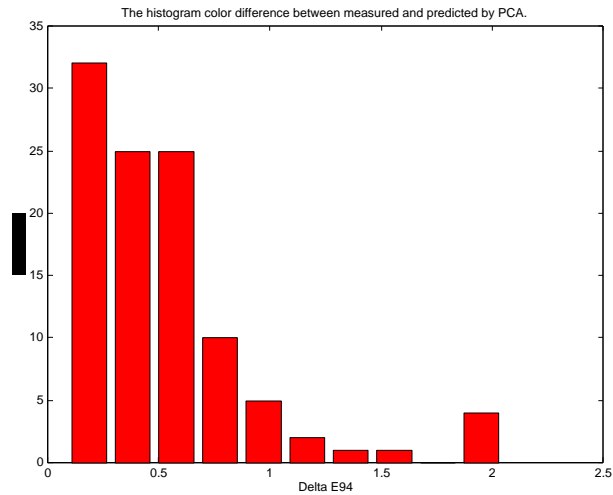
6 eigenvectors; 6 channels (R, G, B with Wratten absorption filters number 38 and 66)

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

Patch	$\Delta E^*_{94}$	reflectance rms error factor	Metameric Index
<b>Average</b>	0.53	0.013	0.40
<b>Std Dev</b>	0.41	0.005	0.32
<b>Max</b>	2.05	0.027	1.68
<b>Min</b>	0.09	0.003	0.01



**Figure 37.** Spectral rms error for spectral reconstruction using 6 eigenvectors; 6 signals: R, G, B with Wratten absorption filters number 38 and 66.

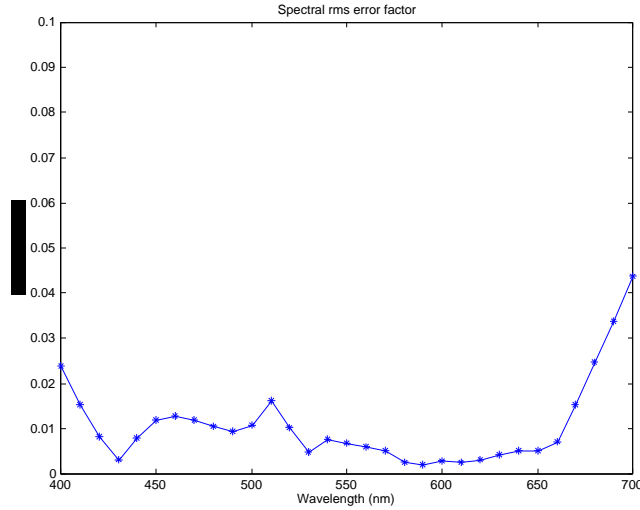


**Figure 38.**  $E^*_{94}$  histogram for spectral reconstruction using 6 eigenvectors; 6 signals: R, G, B with Wratten absorption filters number 38 and 66.

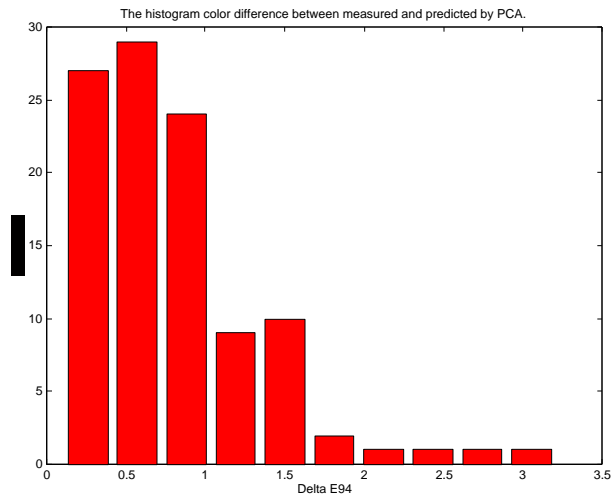
6 eigenvectors; 6 channels (R, G, B with Wratten absorption filter number 66 and with didymium filter)

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

Patch	$\Delta E^*_{94}$	reflectance rms error factor	Metameric Index
<b>Average</b>	0.81	0.014	0.21
<b>Std Dev</b>	0.55	0.006	0.17
<b>Max</b>	3.21	0.029	0.80
<b>Min</b>	0.10	0.004	0.03



**Figure 39.** Spectral rms error for spectral reconstruction using 6 eigenvectors; 6 signals: R, G, B with Wratten absorption filter number 66 and with didymium filter.



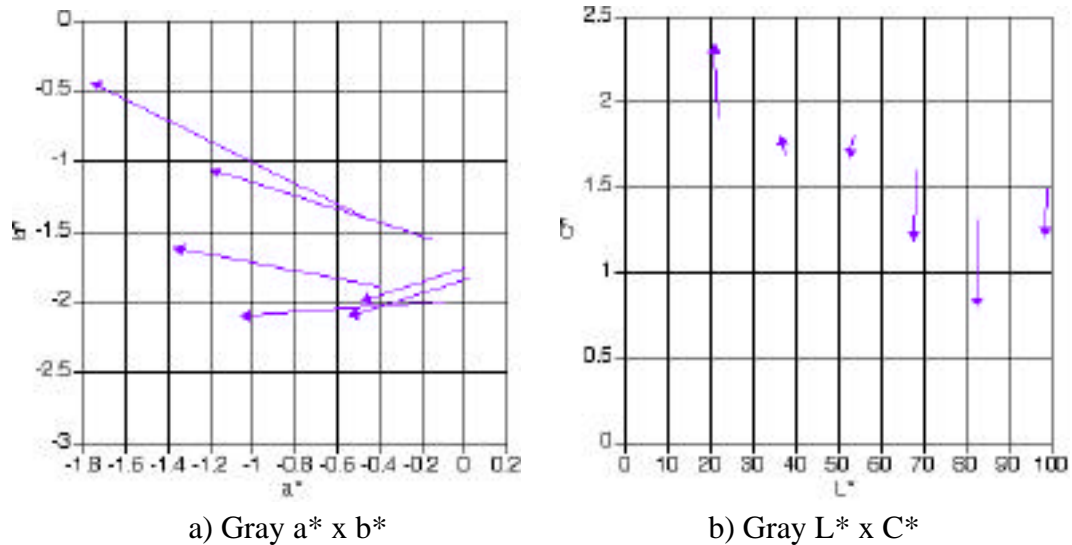
**Figure 40.**  $E^*_{94}$  histogram for spectral reconstruction using 6 eigenvectors; 6 signals: R, G, B with Wratten absorption filter number 66 and with didymium filter.

Observing the results of tables XIII to XVIII and figures 28 to 40 it is possible to see that the combination of trichromatic signals that produced the best colorimetric and spectral performance was using trichromatic signals of the image captured without filter and with light blue filter. However, any combination of trichromatic signals produced reasonable results, with mean  $E^*_{94}$  less than a unity, spectral reflectance rms error equal or less than 2%, and metameric index less than a unity.

**GRAY BALANCE**

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

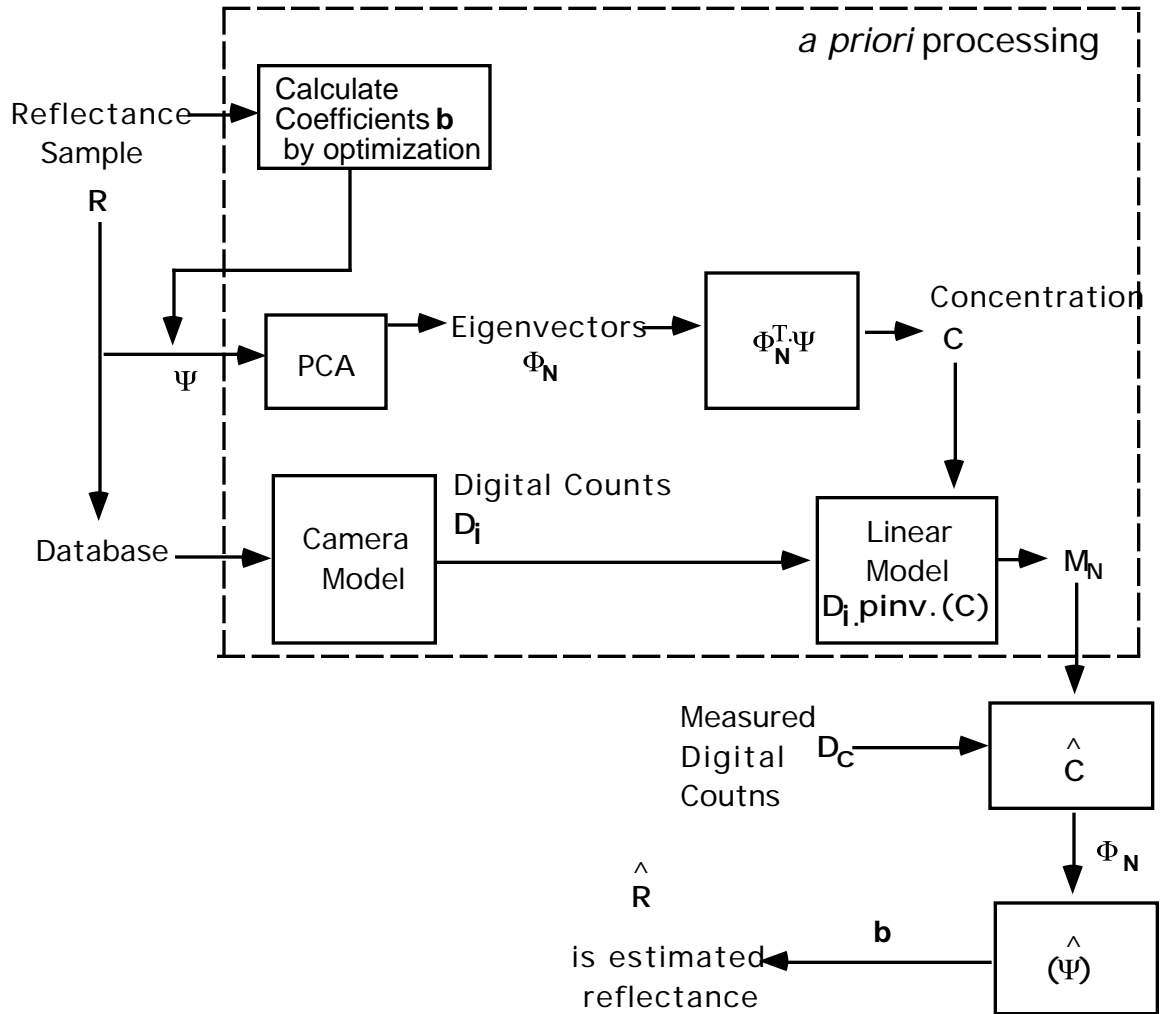
The gray balance graphs is shown in Figures 41a and 41b.



**Figure 41.** Gray balance (original  $\rightarrow$  reproduction) for 6 eigenvectors, 6 channel color reproduction (R, G, B without filter and Wratten filter number 38).

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

This method uses basically the same idea of the linear method above, but instead of using simulated digital counts this method uses measured digital counts averaged from each patch as shown in Figure 42.



**Figure 42.** Flowchart of the linear method using measured digital counts

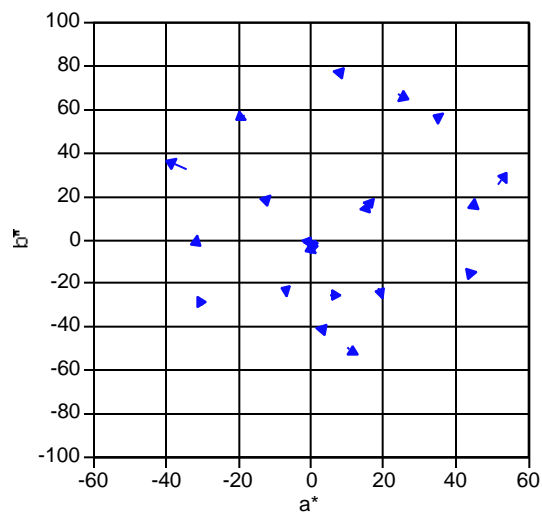
This method was applied to reproduce the colors of 6 eigenvectors and 6 channels and 3 combinations of trichromatic signal pairs. The results are summarized in tables XIX to XXVII and figures 42 to 69.

### TARGET I: Macbeth ColorChecker

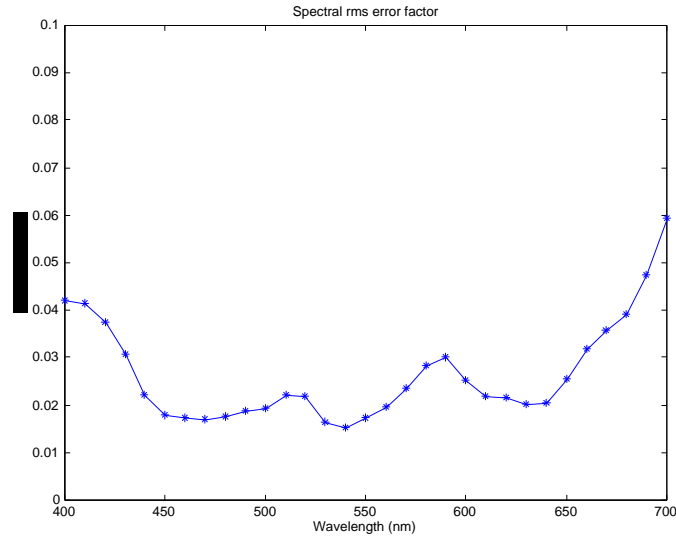
6 eigenvectors and channels (R, G, B without filter and with Wratten filter number 38)

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

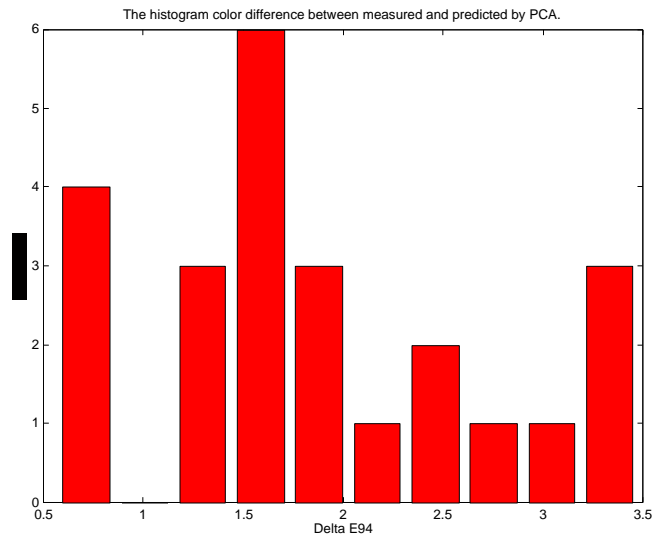
Patch	$\Delta E^*_{94}$	reflectance rms error factor	Metameric Index
Dark skin	1.51	0.016	0.76
Light skin	1.78	0.016	0.49
Blue sky	2.39	0.025	1.58
Foliage	1.29	0.013	0.62
Blue flower	3.18	0.040	0.30
Bluish green	1.57	0.015	0.19
Orange	0.57	0.040	0.99
Purplish red	0.61	0.012	1.18
Moderate red	1.52	0.034	1.16
Purple	2.14	0.066	1.00
Yellow green	1.73	0.027	0.96
Orange yellow	1.59	0.029	0.89
Blue	3.29	0.036	1.82
Green	3.41	0.027	0.25
Red	3.48	0.036	1.97
Yellow	1.28	0.020	0.46
Magenta	1.92	0.030	1.49
Cyan	1.99	0.033	1.03
White	1.72	0.034	0.32
Neutral 8	0.60	0.015	0.11
Neutral 6.5	0.82	0.017	0.60
Neutral 5	1.42	0.017	0.39
Neutral 3.5	2.49	0.011	0.43
Black	2.89	0.005	0.15
<b>Average</b>	<b>1.88</b>	<b>0.029</b>	<b>0.80</b>
<b>Std Dev</b>	<b>0.88</b>	<b>0.013</b>	<b>0.53</b>
<b>Max</b>	<b>3.48</b>	<b>0.066</b>	<b>1.97</b>
<b>Min</b>	<b>0.57</b>	<b>0.005</b>	<b>0.11</b>



**Figure 43.** Colorimetric accuracy using 6 eigenvectors; 6 signals: R, G, B without filter and with Wratten absorption filter number 38; (original -> reproduction).



**Figure 44.** Spectral rms error for spectral reconstruction using 6 eigenvectors; 6 signals: R, G, B without filter and with Wratten absorption filter number 38.

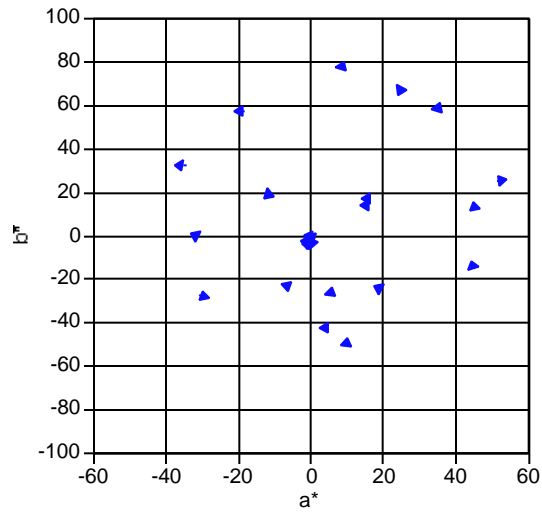


**Figure 45.**  $E^*_{94}$  histogram for spectral reconstruction using 6 eigenvectors; 6 signals: R, G, B without filter and with Wratten absorption filter number 38.

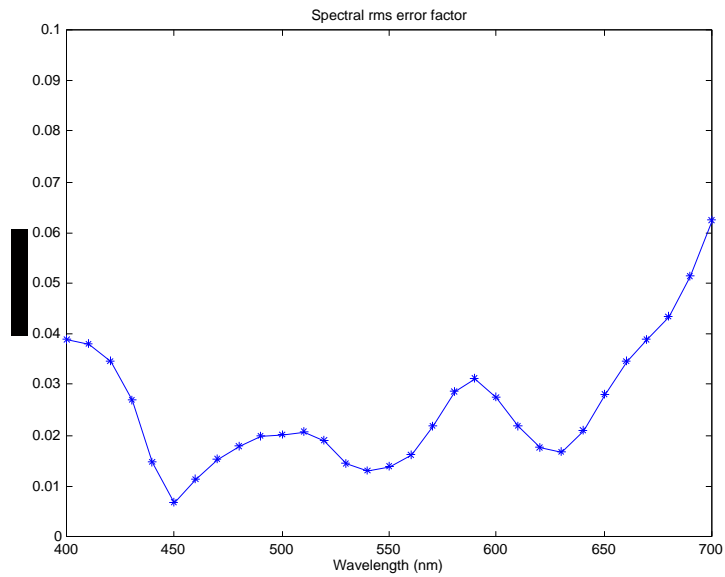
6 eigenvectors and channels (R, G, B without filter and with Wratten filter number 66)

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

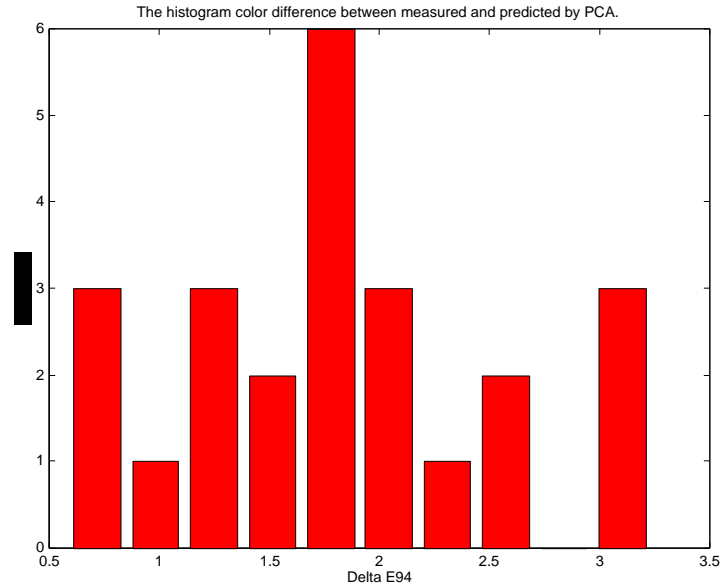
Patch	$\Delta E^*_{94}$	reflectance rms error factor	Metameric Index
Dark skin	1.74	0.015	0.68
Light skin	2.08	0.031	0.50
Blue sky	1.66	0.018	0.08
Foliage	1.73	0.014	0.53
Blue flower	2.08	0.021	0.21
Bluish green	1.58	0.015	0.34
Orange	1.26	0.052	1.40
Purplish red	1.63	0.020	1.33
Moderate red	0.76	0.036	0.79
Purple	2.08	0.066	0.82
Yellow green	1.83	0.021	0.43
Orange yellow	2.45	0.027	0.34
Blue	3.23	0.042	0.81
Green	1.86	0.012	0.30
Red	1.85	0.019	0.35
Yellow	1.01	0.024	0.51
Magenta	1.18	0.038	0.58
Cyan	3.03	0.021	0.33
White	0.58	0.025	0.54
Neutral 8	0.75	0.022	0.72
Neutral 6.5	1.12	0.022	0.90
Neutral 5	2.43	0.019	0.09
Neutral 3.5	2.59	0.013	0.97
Black	2.99	0.004	0.39
<b>Average</b>	<b>1.81</b>	<b>0.028</b>	<b>0.58</b>
<b>Std Dev</b>	<b>0.73</b>	<b>0.014</b>	<b>0.34</b>
<b>Max</b>	<b>3.23</b>	<b>0.066</b>	<b>1.40</b>
<b>Min</b>	<b>0.58</b>	<b>0.004</b>	<b>0.08</b>



**Figure 46.** Colorimetric accuracy using 6 eigenvectors; 6 signals: R, G, B without filter and with Wratten absorption filter number 66; (original -> reproduction).



**Figure 47.** Spectral rms error for spectral reconstruction using 6 eigenvectors; 6 signals: R, G, B without filter and with Wratten absorption filter number 66.



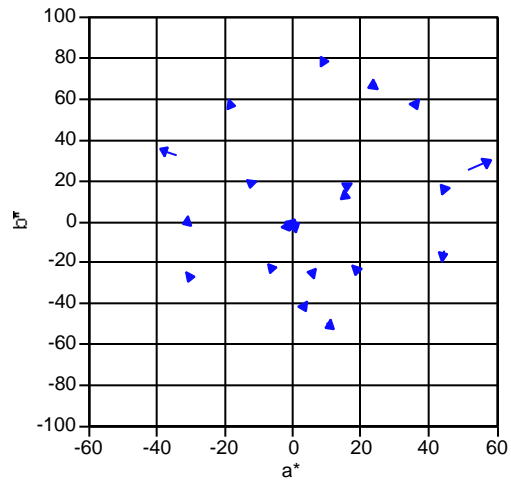
**Figure 48.**  $E^*_{94}$  histogram for spectral reconstruction using 6 eigenvectors; 6 signals: R, G, B without filter and with Wratten absorption filter number 66.

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

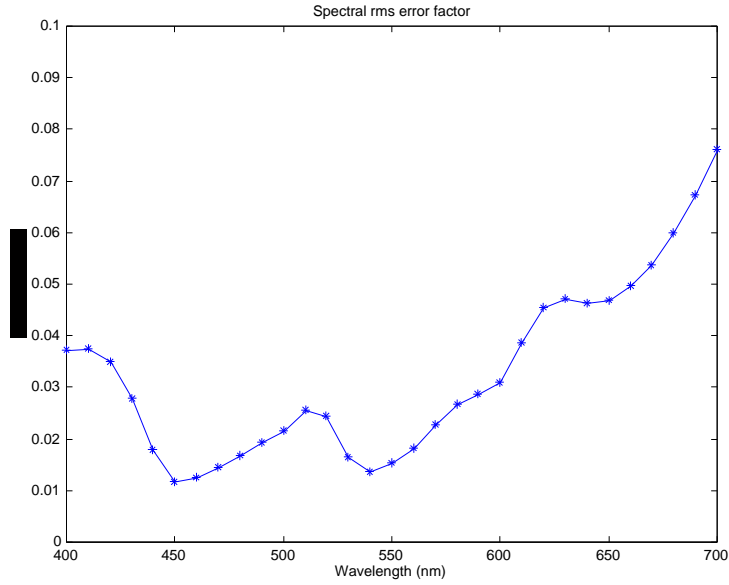
**Table XXI.** Spectral reconstruction using 6 eigenvectors; 6 signals (R, G, B with Wratten absorption filters number 38 and 66).

Patch	$\Delta E^*_{94}$	reflectance rms error factor	Metameric Index
Dark skin	0.81	0.009	0.24
Light skin	2.15	0.016	0.64
Blue sky	3.09	0.027	0.99
Foliage	1.03	0.014	0.58
Blue flower	1.71	0.032	0.89
Bluish green	1.25	0.018	0.33
Orange	1.08	0.035	0.63
Purplish red	1.33	0.013	1.25
Moderate red	1.99	0.042	0.79
Purple	2.32	0.063	0.86
Yellow green	1.66	0.040	1.68
Orange yellow	2.88	0.071	2.49

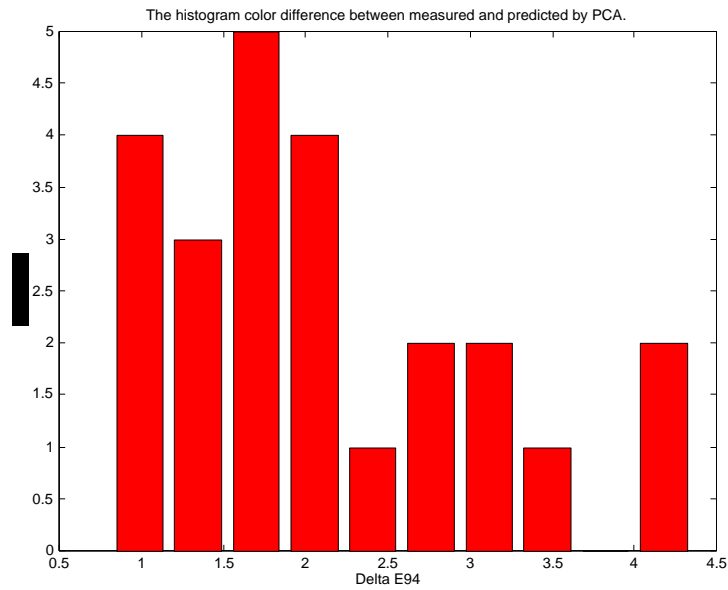
Blue	4.35	0.038	1.22
Green	2.17	0.016	0.28
Red	2.84	0.082	4.50
Yellow	1.44	0.036	0.25
Magenta	3.49	0.036	1.92
Cyan	1.96	0.026	0.92
White	1.68	0.037	0.83
Neutral 8	1.14	0.019	0.03
Neutral 6.5	4.05	0.039	1.01
Neutral 5	1.67	0.019	0.29
Neutral 3.5	3.17	0.015	0.27
Black	1.69	0.005	0.77
<b>Average</b>	<b>2.12</b>	<b>0.037</b>	<b>0.99</b>
<b>Std Dev</b>	<b>0.97</b>	<b>0.019</b>	<b>0.95</b>
<b>Max</b>	<b>4.35</b>	<b>0.082</b>	<b>4.50</b>
<b>Min</b>	<b>0.81</b>	<b>0.005</b>	<b>0.03</b>



**Figure 49.** Colorimetric accuracy using 6 eigenvectors; 6 signals: R, G, B with Wratten absorption filters number 38 and 66; (original -> reproduction).



**Figure 50.** Spectral rms error for spectral reconstruction using 6 eigenvectors; 6 signals: R, G, B with Wratten absorption filters number 38 and 66.



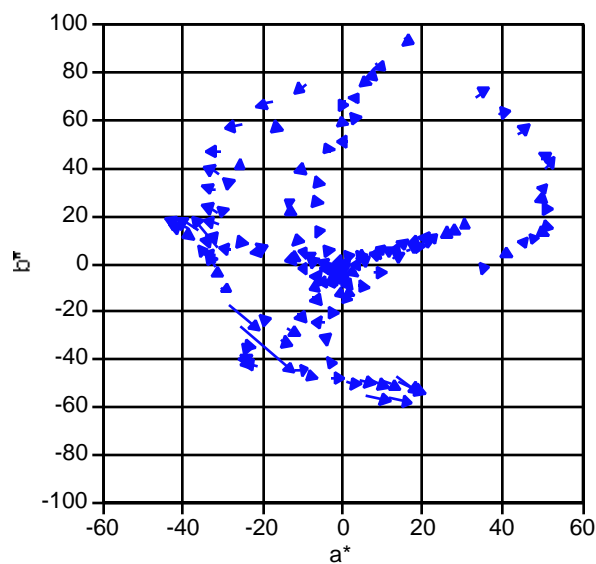
**Figure 51.**  $\Delta E^*_{94}$  histogram for spectral reconstruction using 6 eigenvectors; 6 signals: R, G, B with Wratten absorption filters number 38 and 66.

## Target II: Set of 147 painted patches

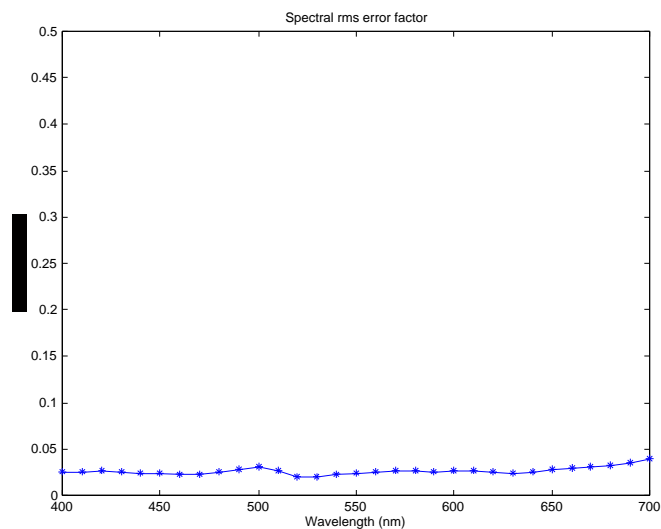
6 eigenvectors and channels (R, G, B without filter and with Wratten filter number 38)

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

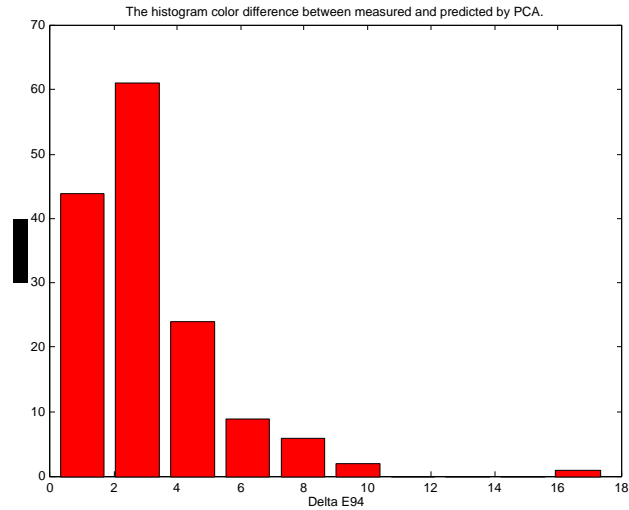
Patch	$\Delta E^*_{94}$	reflectance rms error factor	Metameric Index
<b>Average</b>	3.11	0.027	1.26
<b>Std Dev</b>	2.25	0.015	1.06
<b>Max</b>	17.48	0.076	6.36
<b>Min</b>	0.14	0.003	0.04



**Figure 52.** Colorimetric accuracy using 6 eigenvectors; 6 signals: R, G, B without filter and with Wratten absorption filter number 38; (original -> reproduction).



**Figure 53.** Spectral rms error for spectral reconstruction using 6 eigenvectors; 6 signals: R, G, B without filter and with Wratten absorption filter number 38.

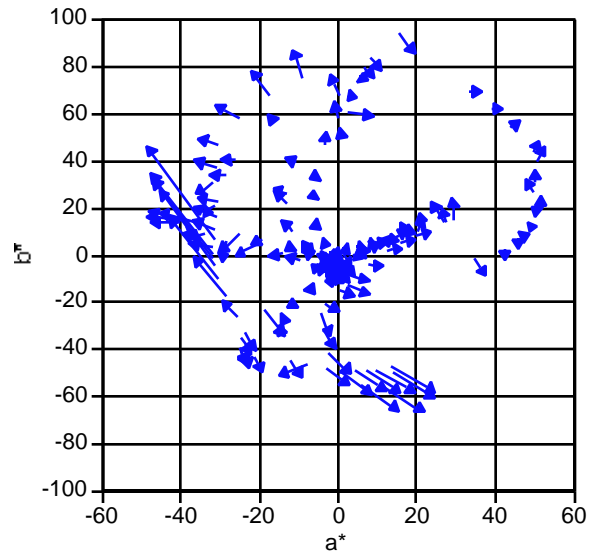


**Figure 54.**  $E^*_{94}$  histogram for spectral reconstruction using 6 eigenvectors; 6 signals: R, G, B without filter and with Wratten absorption filter number 38.

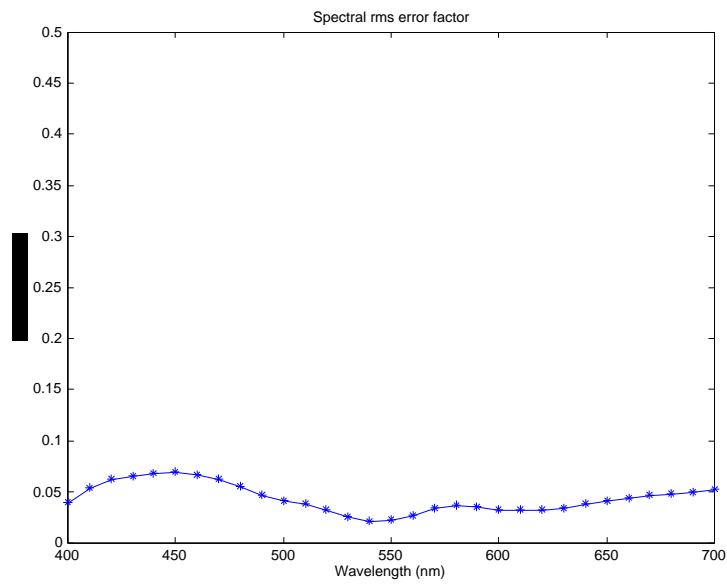
6 eigenvectors and channels (R, G, B without filter and with Wratten filter number 66)

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

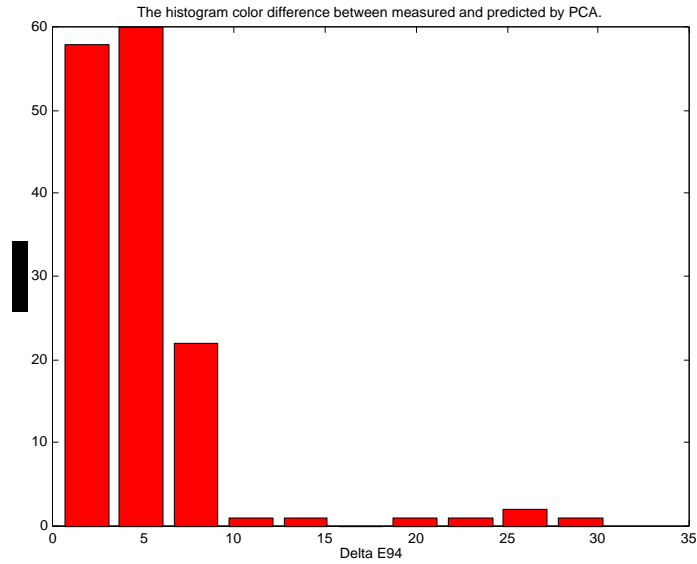
Patch	$\Delta E^*_{94}$	reflectance rms error factor	Metameric Index
<b>Average</b>	5.01	0.046	1.85
<b>Std Dev</b>	4.47	0.029	1.30
<b>Max</b>	30.48	0.124	8.08
<b>Min</b>	0.31	0.006	0.03



**Figure 55.** Colorimetric accuracy using 6 eigenvectors; 6 signals: R, G, B without filter and with Wratten absorption filter number 66; (original -> reproduction).



**Figure 56.** Spectral rms error for spectral reconstruction using 6 eigenvectors; 6 signals: R, G, B without filter and with Wratten absorption filter number 66.

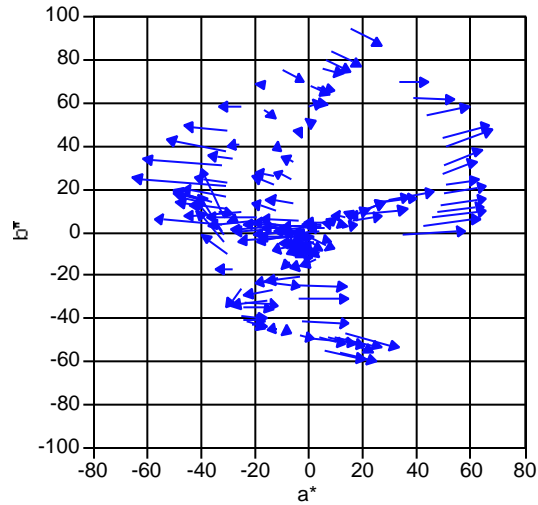


**Figure 57.**  $\Delta E^*_{94}$  histogram for spectral reconstruction using 6 eigenvectors; 6 signals: R, G, B without filter and with Wratten absorption filter number 66.

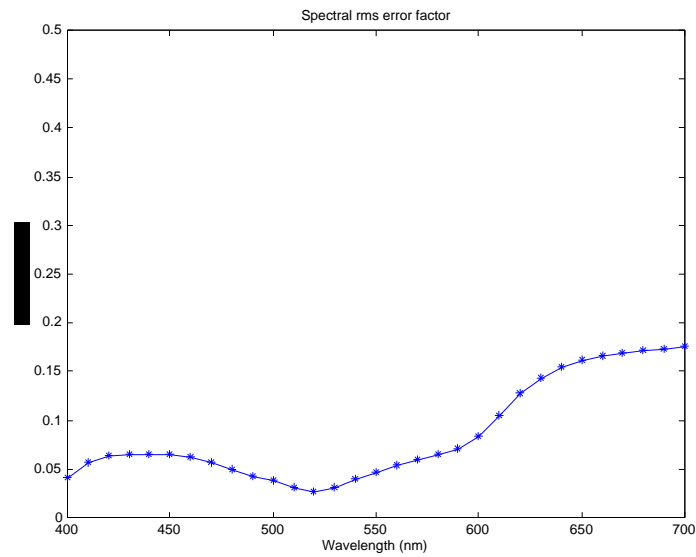
6 eigenvectors and channels (R, G, B with Wratten filters number 38 and 66)

**Table XXIV.** Spectral reconstruction using 6 eigenvectors; 6 signals (R, G, B with Wratten absorption filters number 38 and 66).

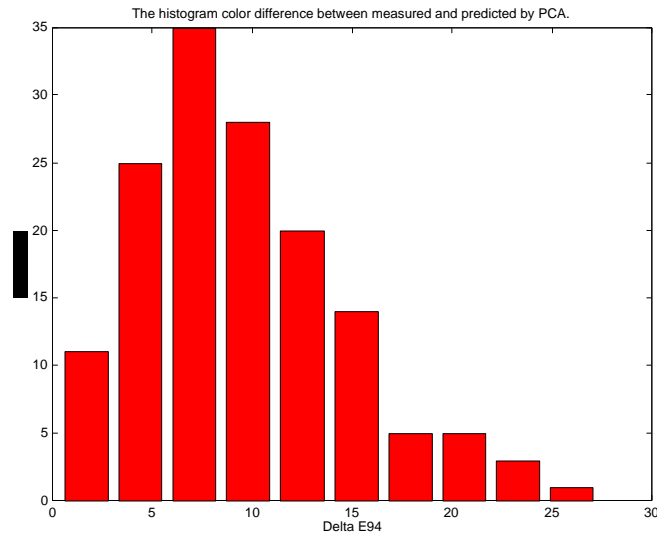
Patch	$\Delta E^*_{94}$	reflectance rms error factor	Metameric Index
<b>Average</b>	9.24	0.100	3.64
<b>Std Dev</b>	4.92	0.067	3.07
<b>Max</b>	25.26	0.332	14.46
<b>Min</b>	0.48	0.004	0.05



**Figure 58.** Colorimetric accuracy using 6 eigenvectors; 6 signals: R, G, B with Wratten absorption filters number 38 and 66; (original -> reproduction).



**Figure 59.** Spectral rms error for spectral reconstruction using 6 eigenvectors; 6 signals: R, G, B with Wratten absorption filters number 38 and 66.



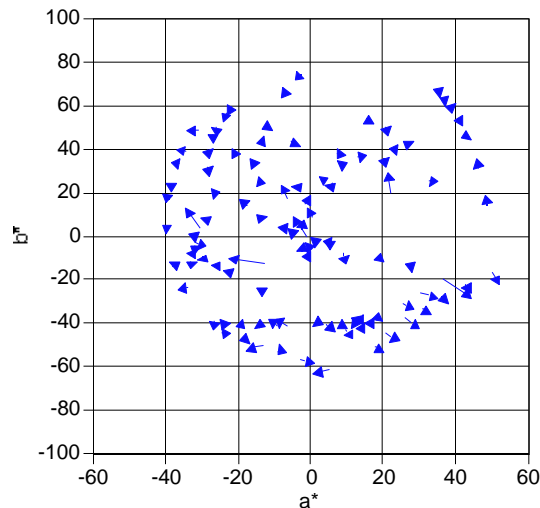
**Figure 60.**  $\Delta E^*_{94}$  histogram for spectral reconstruction using 6 eigenvectors; 6 signals: R, G, B with Wratten absorption filters number 38 and 66.

### Target III: Set of 105 painted patches

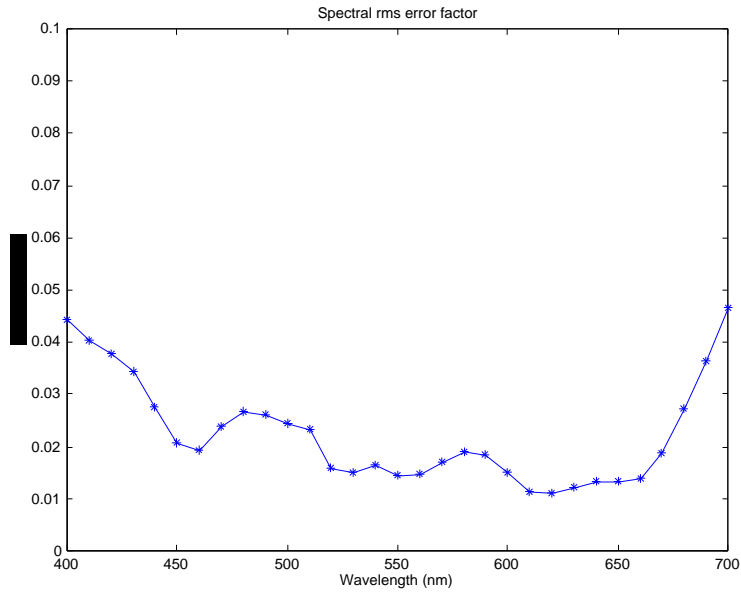
6 eigenvectors and channels (R, G, B without filter and with Wratten filter number 38)

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

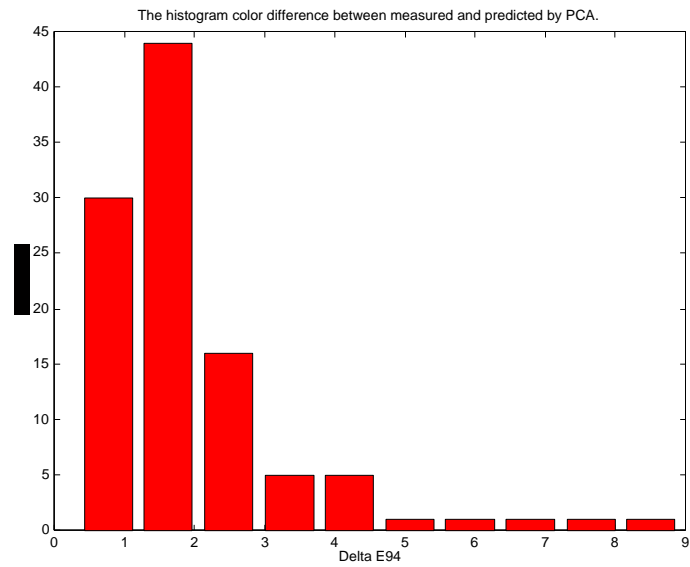
Patch	$\Delta E^*_{94}$	reflectance rms error factor	Metameric Index
<b>Average</b>	1.94	0.025	1.00
<b>Std Dev</b>	1.45	0.010	0.72
<b>Max</b>	8.93	0.055	4.83
<b>Min</b>	0.33	0.008	0.03



**Figure 61.** Colorimetric accuracy using 6 eigenvectors; 6 signals: R, G, B without filter and with Wratten absorption filter number 38; (original -> reproduction).



**Figure 62.** Spectral rms error for spectral reconstruction using 6 eigenvectors; 6 signals: R, G, B without filter and with Wratten absorption filter number 38.

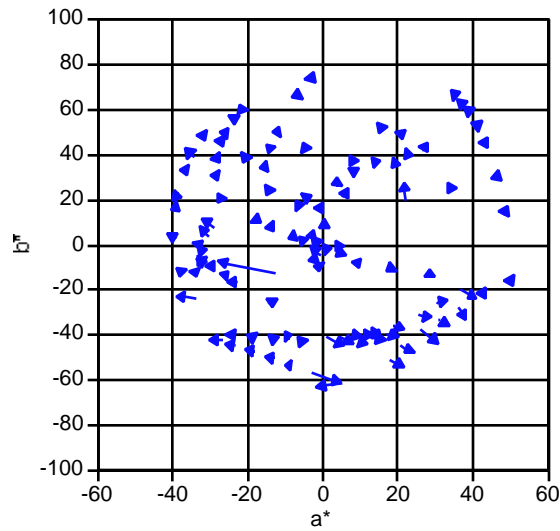


**Figure 63.**  $E^*_{94}$  histogram for spectral reconstruction using 6 eigenvectors; 6 signals: R, G, B without filter and with Wratten absorption filter number 38.

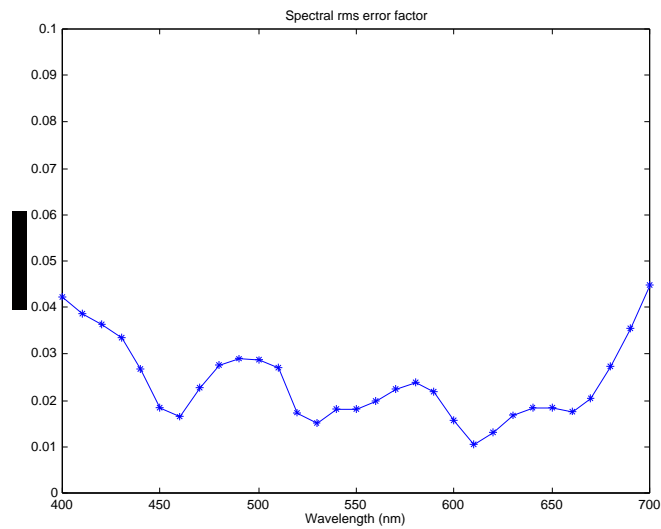
6 eigenvectors and channels (R, G, B without filter and with Wratten filter number 66)

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

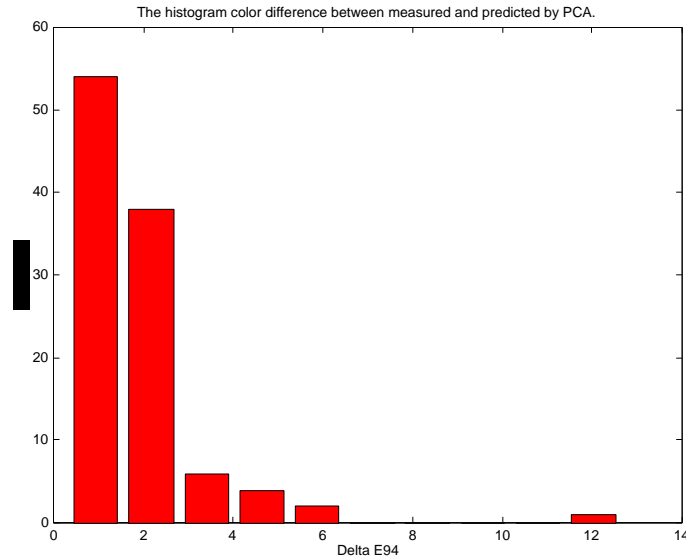
Patch	$\Delta E^*_{94}$	reflectance rms error factor	Metameric Index
<b>Average</b>	1.82	0.025	1.34
<b>Std Dev</b>	1.51	0.010	0.82
<b>Max</b>	12.63	0.055	4.10
<b>Min</b>	0.32	0.009	0.06



**Figure 64.** Colorimetric accuracy using 6 eigenvectors; 6 signals: R, G, B without filter and with Wratten absorption filter number 66; (original -> reproduction).



**Figure 65.** Spectral rms error for spectral reconstruction using 6 eigenvectors; 6 signals: R, G, B without filter and with Wratten absorption filter number 66.

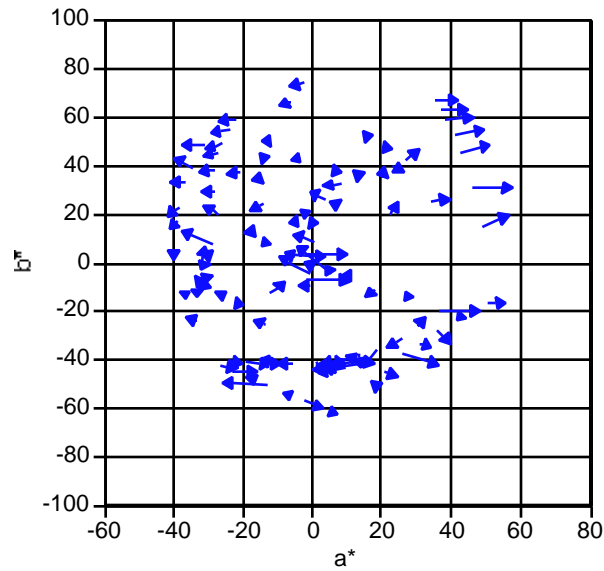


**Figure 66.**  $\Delta E^*_{94}$  histogram for spectral reconstruction using 6 eigenvectors; 6 signals: R, G, B without filter and with Wratten absorption filter number 66.

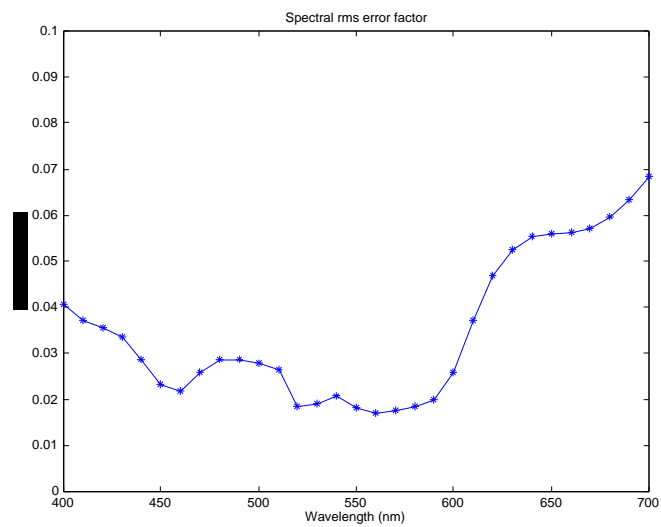
6 eigenvectors and channels (R, G, B with Wratten filters number 38 and 66)

**Table XXVII.** Spectral reconstruction using 6 eigenvectors; 6 signals (R, G, B with Wratten absorption filters number 38 and 66).

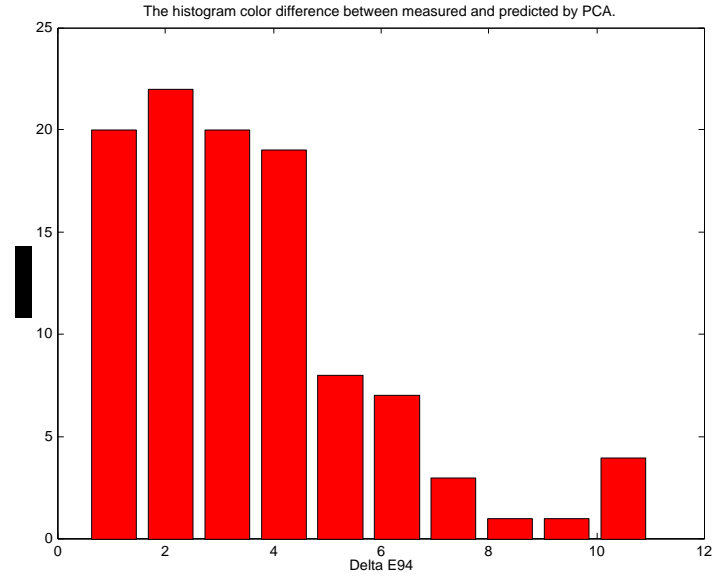
Patch	$\Delta E^*_{94}$	reflectance rms error factor	Metameric Index
<b>Average</b>	3.56	0.038	1.75
<b>Std Dev</b>	2.31	0.018	1.21
<b>Max</b>	11.01	0.113	6.74
<b>Min</b>	0.51	0.010	0.26



**Figure 67.** Colorimetric accuracy using 6 eigenvectors; 6 signals: R, G, B with Wratten absorption filters number 38 and 66; (original -> reproduction).



**Figure 68.** Spectral rms error for spectral reconstruction using 6 eigenvectors; 6 signals: R, G, B with Wratten absorption filters number 38 and 66.



**Figure 69.**  $\Delta E^*_{94}$  histogram for spectral reconstruction using 6 eigenvectors; 6 signals: R, G, B with Wratten absorption filters number 38 and 66.

**Linear method using measured digital counts (Sony Digital Still Camera)**

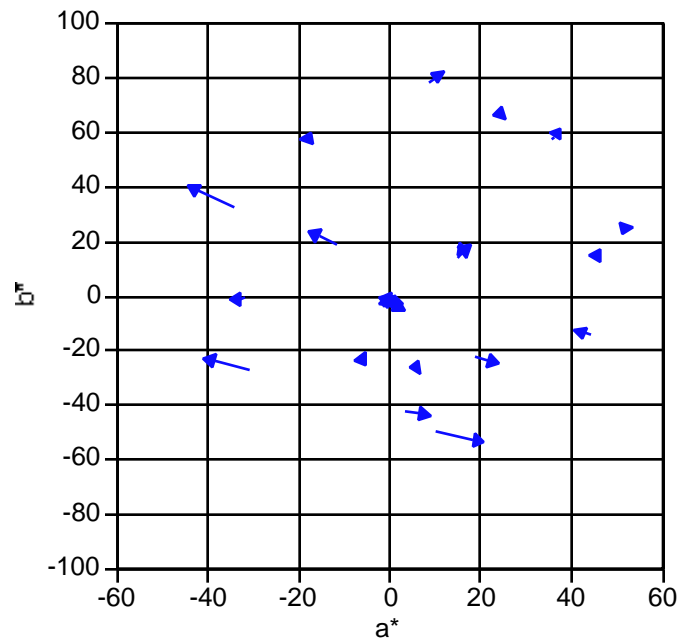
In order to test the performance of the method in new empirical space for a common commercially available digital still camera, the Sony DKC-D5PRO camera was used. The spectral reconstruction from measured digital counts was applied to reproduce the colors of a Macbeth ColorChecker using 6 eigenvectors and 6 channels (R, G, B signals without filter and with Wratten absorption filter number 38). The results are summarized in table XXVIII and figures 70 to 72.

**Table XXVIII.** Spectral reconstruction using 6 eigenvectors; 6 signals : R, G, B without filter and with Wratten absorption filter number 38.

Patch	$\Delta E^*_{94}$	reflectance rms error factor	Metameric Index
Dark skin	11.59	0.070	1.91
Light skin	5.82	0.072	2.24
Blue sky	2.65	0.022	0.77
Foliage	11.31	0.075	1.17
Blue flower	4.96	0.071	1.38

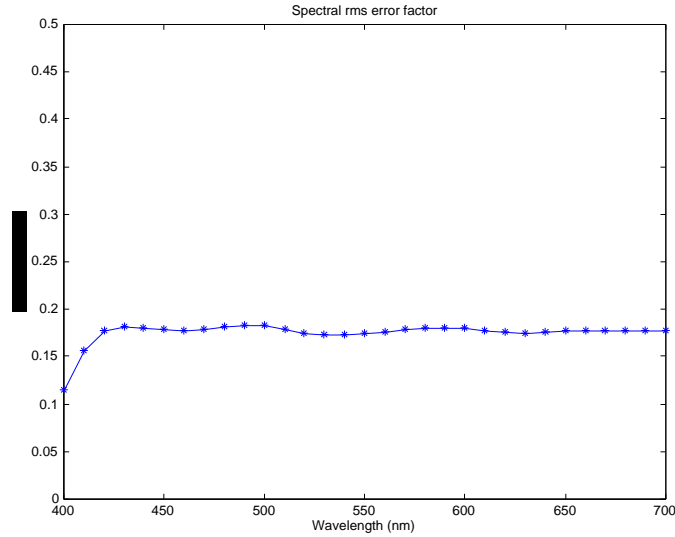
Bluish green	13.16	0.156	6.73
Orange	3.85	0.047	0.69
Purplish red	4.83	0.036	3.21
Moderate red	0.37	0.038	0.58
Purple	5.62	0.035	1.67
Yellow green	6.35	0.079	1.45
Orange yellow	1.49	0.038	1.20
Blue	16.12	0.121	6.40
Green	12.44	0.110	0.94
Red	10.66	0.114	1.76
Yellow	2.10	0.044	0.81
Magenta	4.58	0.069	1.83
Cyan	8.38	0.072	1.10
White	43.49	0.663	18.31
Neutral 8	28.96	0.362	10.28
Neutral 6.5	12.59	0.125	2.35
Neutral 5	2.08	0.017	0.69
Neutral 3.5	15.76	0.099	3.19
Black	34.12	0.186	5.88
<b>Average</b>	<b>10.97</b>	<b>0.176</b>	<b>3.19</b>
<b>Std Dev</b>	<b>10.74</b>	<b>0.137</b>	<b>4.03</b>
<b>Max</b>	<b>43.49</b>	<b>0.663</b>	<b>18.31</b>
<b>Min</b>	<b>0.37</b>	<b>0.017</b>	<b>0.58</b>

Figure 70 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).

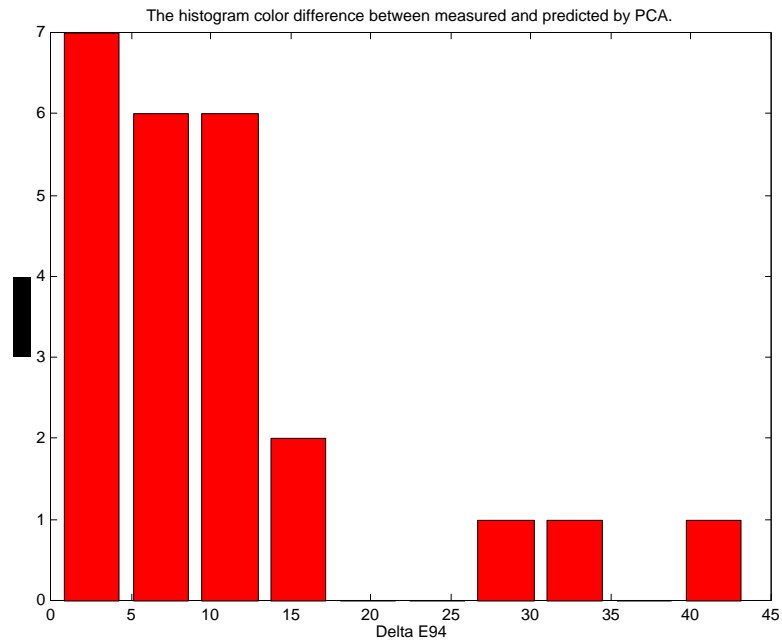


**Figure 70.** Colorimetric accuracy using 6 eigenvectors; 6 signals: R, G, B without filter and with Wratten absorption filter number 38; (original -> reproduction).

Figure 71 and Figure 72 show, respectively, the spectral rms error factor, and the  $E^*_{94}$  histogram for the spectral reconstruction using 6 eigenvectors; 6 signals: R, G, B without filter and with Wratten absorption filter number 38.



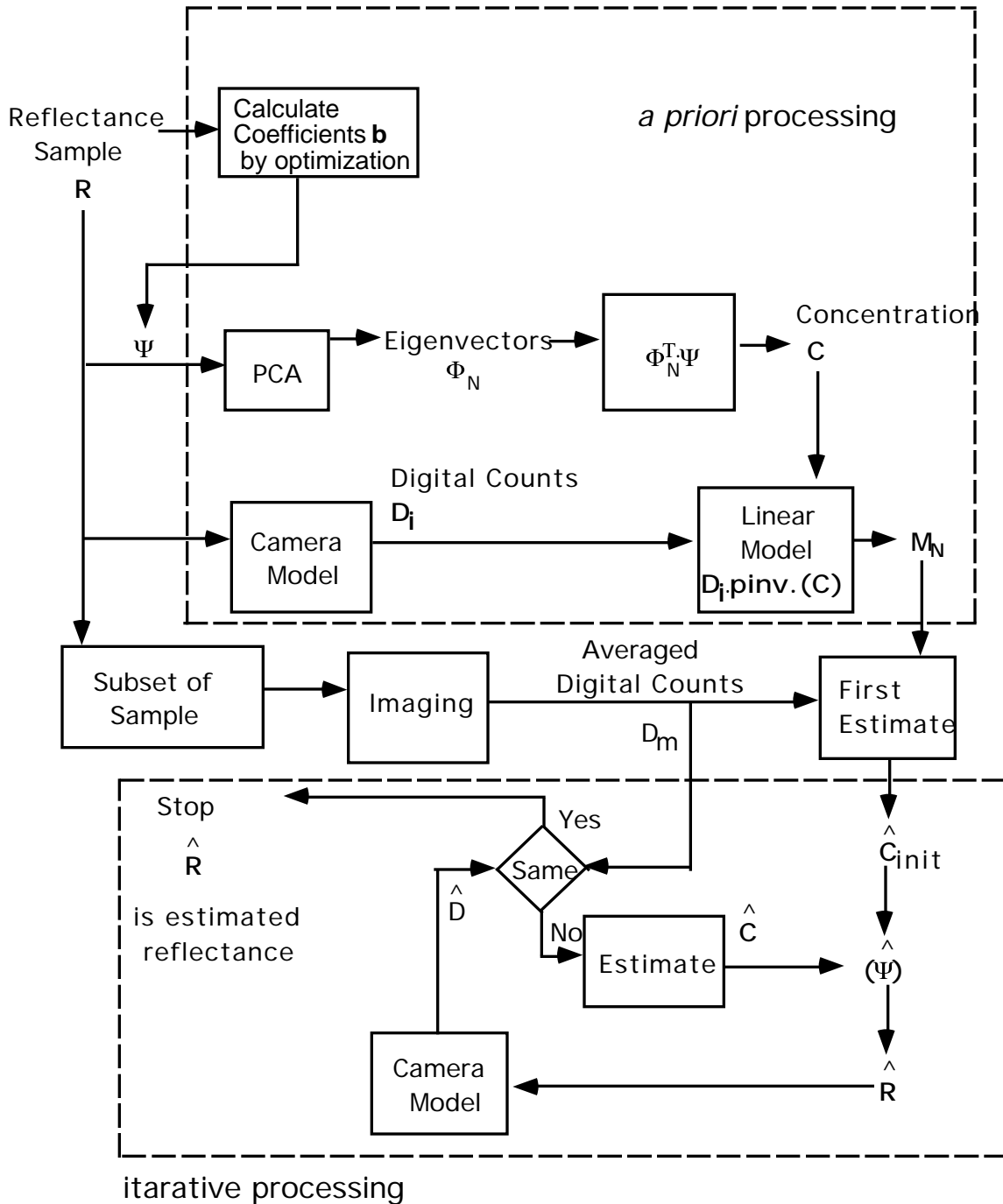
**Figure 71.** Spectral rms error for spectral reconstruction using 6 eigenvectors; 6 signals: R, G, B without filter and R, G, B with Wratten absorption filter number 38.



**Figure 72.**  $E^*_{94}$  histogram for spectral reconstruction using 6 eigenvectors; 6 signals: R, G, B without filter and R, G, B with Wratten absorption filter number 38.

**Iterative method using measured digital counts (Sony Digital Still Camera)**

An attempt to improve the result of the spectral reconstruction using measured two pairs of trichromatic signals from a Sony Digital Still Camera, an iterative method shown in Figure 73 was used.



**Figure 73.** Schematic diagram of the iterative process using linear method to produce the first estimate.

In this iterative method, the first estimate of the concentrations  $\hat{C}_{init}$  is calculated using the linear model using *a priori* calculated transformation matrix  $M_N$ , and the measured digital counts, as presented in the Figure 42. Then, the new empirical space vector  $\hat{\Psi}$  is estimated from  $\hat{C}_{init}$ . The spectral reflectance  $\hat{R}$  is calculated from  $\hat{\Psi}$  and  $\hat{R}$  is used to simulate the digital count  $\hat{D}$ . If the difference between estimated digital count

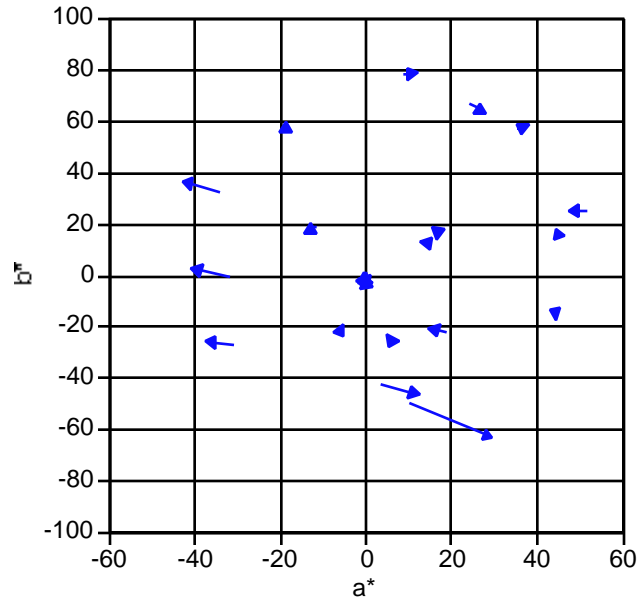
$\hat{\mathbf{D}}$  and the measured digital count  $D_m$  is more than a pre-determined value (in this experiment =1), it estimates again the coefficient  $\hat{\mathbf{C}}$  and it iterates re-calculating  $\hat{\mathbf{R}}$  until the difference between estimated and measured digital counts are less than .

The simulations was performed for a spectral reconstruction using 6 eigenvectors, 6 signals (R, G, B without filter and with Wratten absorption filter number 38) and the results is presented in table XIX and figures 74 to 76. Simplex method was used in the simulation. Every patch converged after 7 iterations.

**Table XXIX.** Spectral reconstruction using 6 eigenvectors; 6 signals : R, G, B without filter and with Wratten absorption filter number 38.

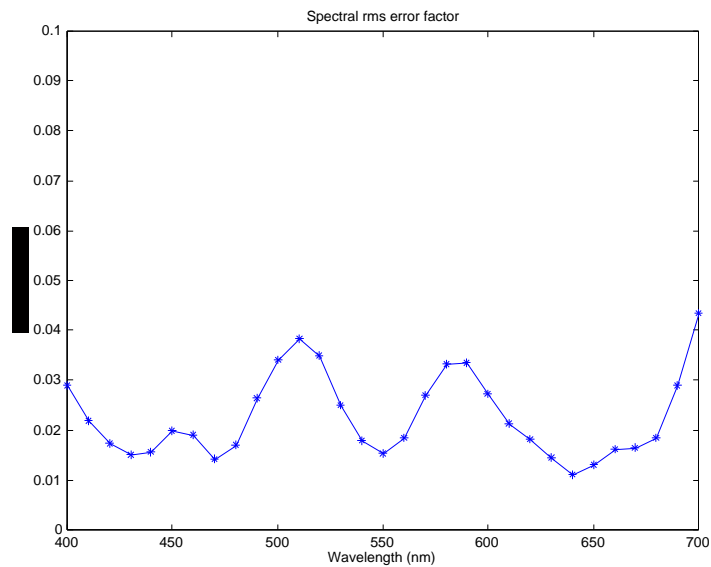
Patch	$\Delta E^*_{94}$	reflectance rms error factor	Metameric Index
Dark skin	0.62	0.007	0.33
Light skin	1.29	0.021	0.86
Blue sky	2.58	0.019	0.64
Foliage	2.67	0.015	1.13
Blue flower	1.41	0.015	0.49
Bluish green	5.07	0.038	1.47
Orange	1.01	0.030	1.53
Purplish red	5.54	0.024	2.66
Moderate red	1.64	0.028	0.96
Purple	3.08	0.031	1.75
Yellow green	1.99	0.025	0.90
Orange yellow	2.05	0.037	1.76
Blue	14.63	0.037	3.42
Green	3.52	0.025	1.90
Red	1.44	0.029	1.16
Yellow	1.63	0.028	0.38
Magenta	0.67	0.020	0.36
Cyan	3.31	0.023	2.32
White	2.53	0.027	0.17
Neutral 8	1.60	0.014	0.24
Neutral 6.5	3.04	0.017	0.45
Neutral 5	3.39	0.012	0.24
Neutral 3.5	2.89	0.007	0.08
Black	2.38	0.004	0.28
<b>Average</b>	<b>2.92</b>	<b>0.024</b>	<b>1.06</b>
<b>Std Dev</b>	<b>2.78</b>	<b>0.009</b>	<b>0.88</b>
<b>Max</b>	<b>14.63</b>	<b>0.038</b>	<b>3.42</b>
<b>Min</b>	<b>0.62</b>	<b>0.004</b>	<b>0.08</b>

Figure 74 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).

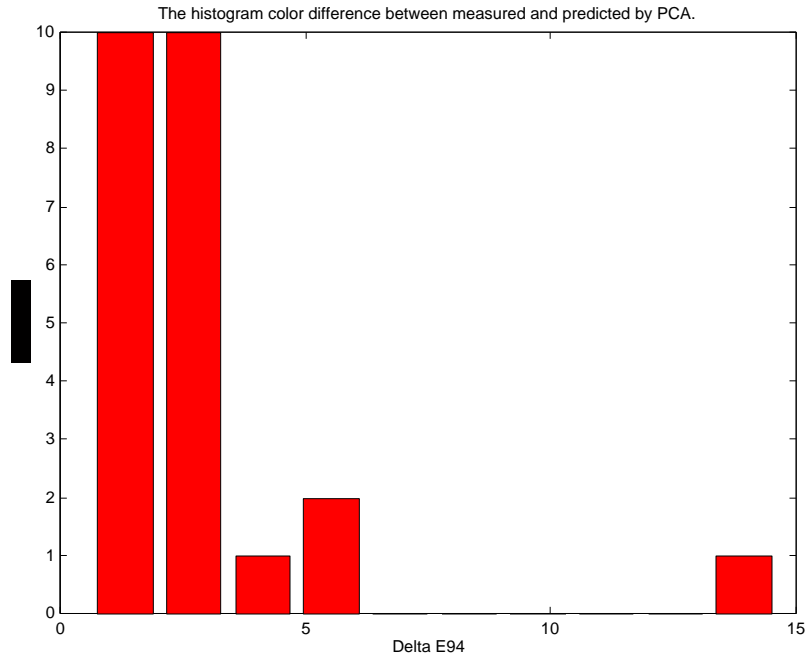


**Figure 74.** Colorimetric accuracy using 6 eigenvectors; 6 signals: R, G, B without filter and with Wratten absorption filter number 38; (original -> reproduction).

Figure 75 and Figure 76 show, respectively, the spectral rms error factor, and the  $E^*_{94}$  histogram for the spectral reconstruction using 6 eigenvectors; 6 signals: R, G, B without filter and with Wratten absorption filter number 38.



**Figure 75.** 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 38.



**Figure 76.**  $E^*_{94}$  histogram for spectral reconstruction using 6 eigenvectors; 6 signals: R, G, B without filter and R, G, B with Wratten absorption filter number 38.

The iterative method could improve the results obtained by linear method. The performance was not better because of one patch (blue patch) with  $E^*_{94}$  more than 14. It is possible that the low digital counts for this patch is affected by noise and therefore different of the simulated digital counts using the camera model. Most of the reconstructed spectral curves using linear model were shifted in amplitude as indicate the curve in the Figure 72. It shows that there was some systematic error from the measured and predicted spectral reflectances. The iterative method was effective to correct this kind of error.