Benefits and Drawbacks of two Methods for Characterizing Digital Cameras

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Abstract

*In order to perform quantitative evaluation of a camera colour measurement quality, two characterization approaches were performed and compared: measuring the spectral sensitivity of the R G B channels, and using a least square fitting of L*a*b* coordinates of a collection of reference samples.*

Purpose

A restorer who has completed a cleaning or a restoring procedure on an artwork usually includes a photograph in his (her) report. Nowadays, digital cameras are used which changes the restorers habits.

We ran different procedures to characterize digital cameras:

- Measuring the spectral sensitivity of the R G B channels
- Least square fitting to L*a*b* coordinates of a colour data basis

Methods

Procedure # 1: Measuring spectral sensitivities

We set an optical bench in the laboratory and measured the *S*r *S*g *S*b spectral sensitivities of the camera using the standard protocol described by IEC (2003).

A diffuser was illuminated with a series of monochromatic radiations that were desaturated by an additional constant white light adjusted so that all RGB digital image data for red, green and blue channels would be positive and non-zero.

Any stray light and second-order spectrum were stopped.

A chart including control grey scales surrounded the diffuser. It was illuminated by two light projectors balanced in terms of colour temperature (5000 K ±250 K) and illuminance.

All light sources were driven by stabilised power supply.

We also shot a series of grey chips.

*Procedure # 2: Optimizing L*a*b* transformation*

Test charts, measurement conditions and methods of measurement were prepared according to the same normative reference recommendations as in procedure #1.

We shot sequentially a collection of 93 NCS samples plus a series of grey chips with known spectral reflectance, widely distributed in terms of hue, lightness and blackness. Each sample was placed at the centre of the control chart. We intentionally underexposed all images in order to avoid saturating the colour channels of the digital camera, which could occur with yellow and orange patches.

Methods common to the two procedures

Characterization was performed using a "NIKON Coolpix 950" camera. This model allows using an "MEMO EXPO" mode that blocks the exposition throughout several series of shots. We simultaneously shot the image and recorded the sample tristimulus values using a Minolta CS-1000 spectroradiometer.

In procedure #2, we slightly raised the illuminance provided by the two light projectors in a fixed ratio throughout the series of shots in order to avoid under exposure of the Minolta CS1000 spectroradiometer.

We saved the files in TIF format and wrote the software in MatLab language.

Results

Spectral sensitivities

Tone characteristics

To obtain tone characteristics, we inserted sequentially 15 grey chips at the centre of the control chart. The luminance of each grey chip was measured using the Minolta CS1000 spectroradiometer while the digital camera shot the chart. The digital data obtained for each grey chip are then compensated to eliminate the autonomous exposure control using the recorded data for the grey steps in the control chart. Graphical representation of the camera three channels (R,G,B) characteristics were obtained plotting output levels versus grey chips luminance. Measurements show that the three normalized outputs have not a linear variation with increasing input light level. Despite a little difference between the R, G and B channels, the three curves have the same shape that seems to be equal to the inverse function of a CRT screen gamma curve (Fig. 1).

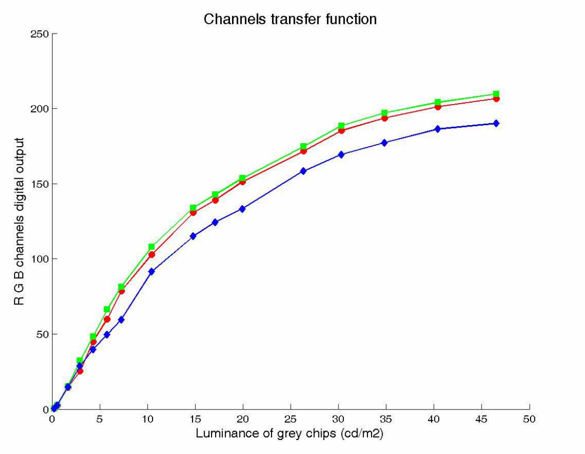

Figure 1. R G B channels characteristics

Measuring the response of the colour channels

A series of shots of desaturated monochromatic radiations was made and compared to direct spectroradiometric measurements. After correcting for the non-linear luminance transfer function of the camera, the contribution of the additional white light was excluded and spectral sensitivities were derived for monochromatic lights. Figure 2 shows the spectral sensitivities of the "Nikon Coolpix 950" camera. Data at 380 and 390 nm were smoothed.

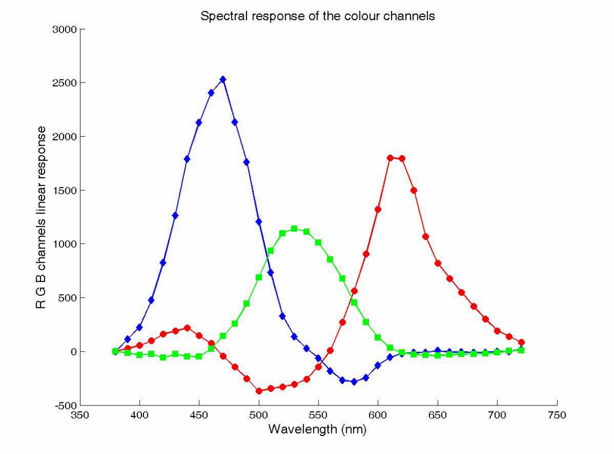

Figure 2. Experimental spectral sensitivities of a Nikon Coolpix 950 digital camera. Exposure of the camera was fixed over the spectrum.

Modelling the spectral sensitivities

The profiles of the response curves of the camera (not shown in the paper) are qualitatively similar to expectation for displaying the images on a standard monitor. A second order tri-linear model allows to adjust at best the experimental spectral sensitivities of the camera to the CIE standard colorimetric observer (Fig. 3). Indeed, we noted that a first order tri-linear model could not make a satisfying transformation.

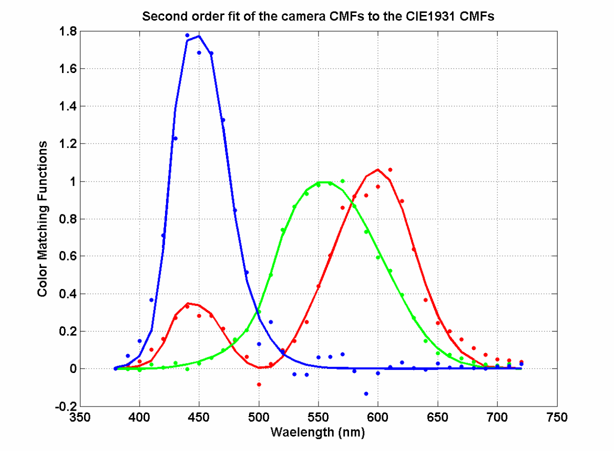

Figure 3: Second order tri-linear model (lines) adjusted to the CIE standard colorimetric observer (circles)

Least square fitting to L*a*b* coordinates

Failure of the sRGB conversion

We use the RGB digital output values of the camera for the series of grey chips and for the collection of 93 NCS samples. By using the previously determined camera tone characteristics, we calculated sRGB tristimulus values of each sample. Then, by applying the sRGB conversion matrix, we transformed them to 1931 CIE XYZ values. We evaluated the camera colour measurements quality by calculating, for each sample, the colour difference between the (L*, a*, b*) values given by the spectroradiometer and the (L^*_{cam}, a^*_{cam}, b^*_{cam}) values derived from the digital camera measurements. We obtained a mean colour difference of 11.58 unities with a ΔEmax = 31.03 unities and a ΔEmin = 2.9. These large colour differences show that the digital camera has not a high colour measurement quality.

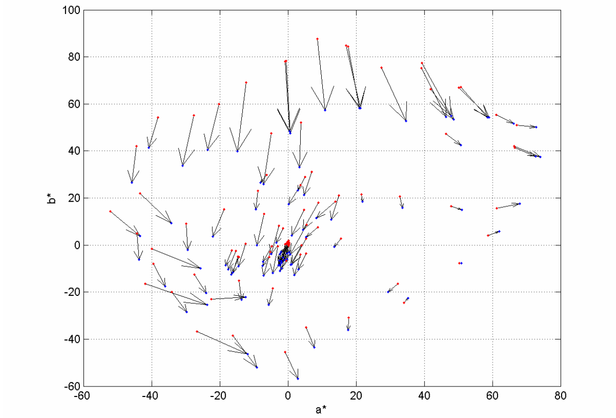

*Figure 4. Colour differences between the camera measurements and the NCS samples CIELAB colour coordinates plotted in the a*b* plane.*

As shown in Figure 4 and Figure 5 the colour difference is the most pronounced for the samples situated in the periphery of the camera gamut. The arrows also indicates the highest colour difference in the b* direction and the lowest in the L* direction.

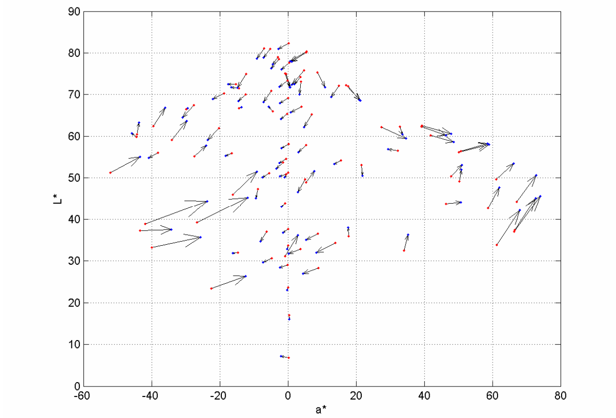

*Figure 5. Colour differences between the camera measurements and the NCS samples CIELAB colour coordinates plotted in the a*L* plane*

Optimized fit

To improve this camera colour measurements we performed a linear colour-correction that transforms the RGB digital output values to the samples tristimulus values in the CIE standard colorimetric space. As reported in previous works [1-5], the linear transformation is more efficient when applied in the CIELAB colour space. With the 93 NCS colour samples a non-negligible part of the colour space is covered.

Again, by using the previously determined camera tone characteristics, we calculated sRGB tristimulus values for each sample. Then we derived the corresponding coordinates (L^*_{cam}, a^*_{cam}, b^*_{cam}) in the CIELAB colour space. The matrix coefficients of the linear transformation were then determined by fitting the (L^*_{cam}, a^*_{cam}, b^*_{cam}) to the samples values (L^*, a^*, b^*) in the CIELAB standard and by using the least squares criteria. With this transformation method, we lowered the colour differences between the camera colour measurements and the CIELAB values of the colour samples.

With a third order fit we obtained a mean colour difference ΔE_{mean} of 2.41 unities, a 0.19 unities as a minimum colour difference value ΔE_{min} and 7.99 unities for the maximum colour difference ΔE_{max}.

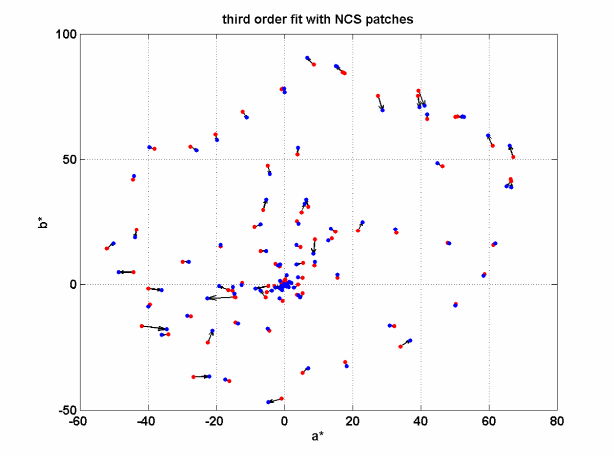

*Figure 6. Colour differences after a third order fit of the camera measurements to the NCS samples CIELAB colour coordinates plotted in the a*b* plane.*

Figure 6 and figure 7 plots the colour difference in the a*b* plan and in the a*L* plan. We can see that the b* component of the colour difference is reduced (compare with Figure 4 and Figure 5). Some samples still show non-negligible colour differences.

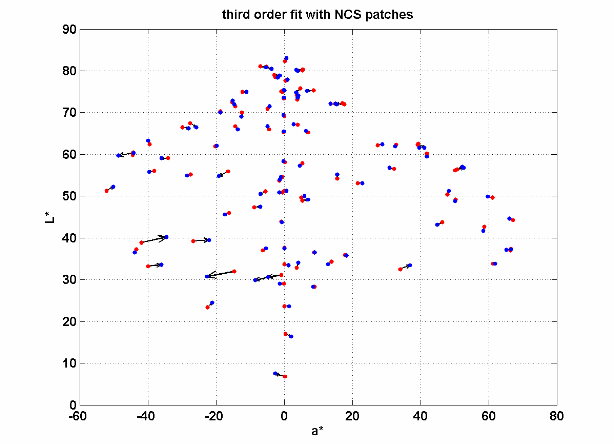

*Figure 7. Colour differences after a third order fit of the camera measurements to the NCS samples CIELAB colour coordinates plotted in the a*L* plane.*

A fourth order linear fit with the mean squares criteria is performed on the same set of 93 NCS color samples. We obtained a mean colour difference ΔE_{mean} of 1.79 unities, a 0.34 unities as a minimum colour difference value ΔE_{min} and 6.42 unities for the maximum colour difference ΔE_{max}.

The plots of the colour difference in the a*b* and a*L* are respectively shown Figure 8 and Figure 9. The colour differences are even more reduced than with a third-order fit. Nevertheless, this improvement might not benefit to the application of the regression to an unknown set of samples.

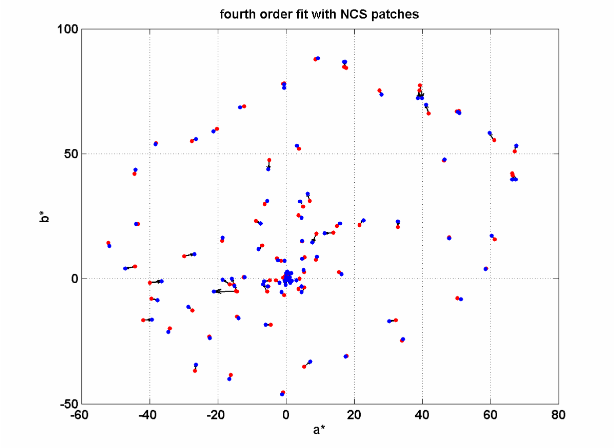

*Figure 8. Colour differences after a fourth order fit of the camera measurements to the NCS samples CIELAB colour coordinates plotted in the a*b* plane*

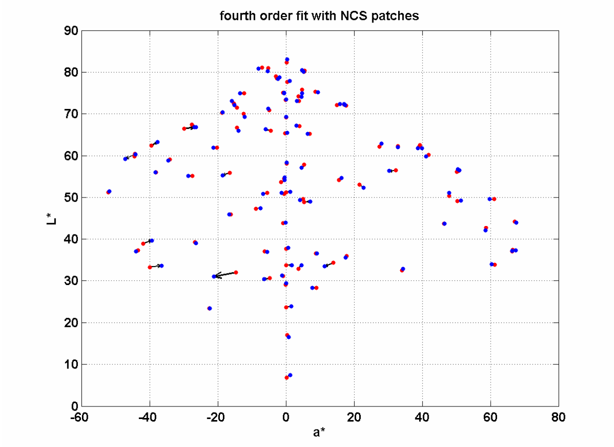

*Figure 9. Colour differences after a fourth order fit of the camera measurements to the NCS samples CIELAB colour coordinates plotted in the a*L* plane*

Validation

It is well known that the regression determined using a given set of colour samples should be efficient when predicting colour coordinates of unknown samples as long as they have identical spectral properties.

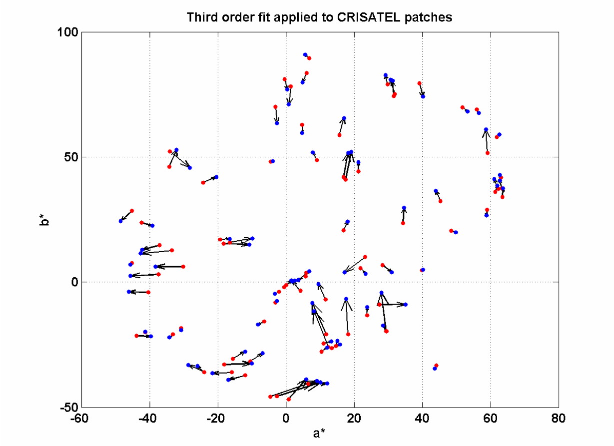

*Figure 10. Colour differences, plotted in the a*b* plane, obtained by applying the third order fit to CRISATEL acrylic samples*

However, to evaluate the robustness of the regression, we decided to apply the regression derived from the NCS samples to 81 samples from the CRISATEL acrylic chart. These samples have spectral properties different from those of the NCS samples and are highly saturated. Thus they should be the good candidates for testing a possible failure of the regression.

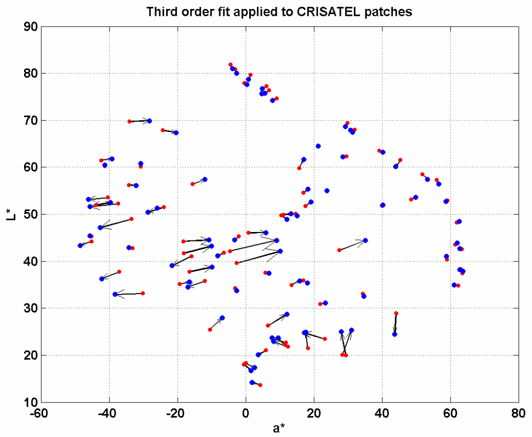

*Figure 11. Colour differences, plotted in the a*L* plane, obtained by applying the third order fit to CRISATEL acrylic samples*

Applying the third order regression derived from the NCS set, to the CRISATEL acrylic samples, we obtained a mean colour difference ΔEmean of 5.25 unities, a 0.35 unities as a minimum colour difference value ΔEmin and 16.27 unities for the maximum colour difference ΔEmax. The fact that the mean colour difference remains high arises from some saturated CRISATEL acrylic samples. The remaining acrylic samples seem to give acceptable colour differences (see Figure 10 and Figure 11). This result comforts the robustness of the regression method using the least squares fitting criterion.

On the other hand, the CRISATEL samples that give the highest colour differences are those situated in the border or out of the colour gamut of the NCS samples. The regression method may be ameliorated by using more NCS samples and covering an extended colour space.

Benefits and drawbacks of the two methods

Method based on the spectral sensitivities

Measuring the spectral sensitivities of the camera needs a rather sophisticated laboratory set-up. Adjusting the intensity of the additional desaturating white light in order to avoid saturating the colour signals captured by the camera is decisive for the success of the experiment.

The need of a second-order tri-linear regression instead of a first order tri-linear regression probably originates from the mismatch of the spectral sensitivities of the sensors with the sRGB standards, as well as from a lack of accuracy of the satured colour signals at the peak wavelengths of the spectral sensitivity functions.

As the method yields spectral data, we expect that it would predict unknown surfaces tristimulus values under any illuminant provided its spectral power distribution is known.

Nevertheless, the improvement brought by the second-order fitting to the CIE colour-matching functions, probably due to the increased number of fitting coefficients, might well be at the expense of a degradation of prediction for an unknown collection of samples.

Method based on the a collection of samples

The second method based on the fit of the camera measurements seems to be efficient as it gives acceptable results. In order to guarantee a good regression of the camera measurement, the target should contain a large number of colour samples to cover the total colour gamut. However the regression efficiency is dependent upon the digital camera color measurement quality.

Saturation of the response of the colour channels

The two methods suffer from possible saturation of colour captured signals with highly saturated samples. We would recommend to under-expose the image for the characterization and validation with unknown samples. In the future, the advantage of underexposure will have to be evaluated if one of the procedures is to be used for characterizing the camera of a restorer who manipulates highly saturated pigmented colours.

Conclusion

We explored two procedures to characterize a digital camera.

Measuring spectral sensitivities yield data qualitatively and quantitatively consistent with the human observer. Data could be used to predict XYZ tristimulus values of neutral and highly saturated colour surfaces under any spectrally known illuminant provided the luminance transfer function is used. Unfortunately a dedicated optical bench is needed.

Least square fitting on a colour data basis directly yields XYZ tristimulus values coordinates. It predicts unknown L* a* b* coordinates of a validation set of CRISATEL samples with a mean ΔE_{ab} error equal to 5.26. It is easy to perform provided the illuminant is fixed. Improved fit is obtained when the luminance transfer function is used

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Author Biography

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