COLOR CALIBRATION OF AN ACQUISITION DEVICE

Method, Quality and Results

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Abstract: Color calibrated acquisition is of strategic importance when high quality imaging is required, such as for work of art imaging. The aim of calibration is to correct raw acquired image for the various acquisition device signal deformation, such as noise, lighting uniformity, white balance and color deformation, due, for a great part, to camera spectral sensitivities. We first present reference color data computation obtained from camera's spectral sensitivities and reflectance of reference patches, taken form Gretag MacBeth Color Chart DC. Then we give a color calibration method based on linear regression. We finally evaluate the quality of applied calibration and present some resulting calibrated images.

1 INTRODUCTION

This study presents a method of calibration for a color acquisition system. Once the whole system has been characterized, the next step consists in calibrating this system to get data that are independent face to all possible acquisition system parameters evolution during the various acquisition.

In order to be able to carry out such a calibration method, the color data which will stand as reference for calibration must be determined. In this purpose, the most accurate estimation of acquisition system spectral sensitivity curves has to be performed. Error computation from results of the various known methods allows to select the method providing the best results. This study describes some methods and results.

Calibration methods can then be developed. We present the established calibration method for our system, with analysis on its quality, and on its carrying out on some works of art.

Image acquisition process is known as interaction between illumination spectral distribution, object spectral reflectance and imaging system characteristics. We denote the linearized sensor response for the k^{th} channel (R, G or B, or monochrome) by C_k, the linearization function by F, the exposure time by e, the sensor noise for the k^{th} channel by b_k, the sensor spectral sensitivity function for the k^{th} channel $S_k(\lambda)$, by $L(\lambda)$ the total incident light on sensor (illumination * reflectance) and the spectral range $[\lambda_l - \lambda_h]$. The camera response C_k, for an image pixel, is determined by equation (1).

$$C_k = F\left(e \sum_{\lambda=\lambda_l}^{\lambda_h} S_k(\lambda) L(\lambda) \Delta\lambda + b_k \right) \qquad (1)$$

2 REFERENCE COLOR DATA

Our calibration aims to transform acquired raw RGB data to a fixed and determined RGB space, in order to get similar and comparable color data, whatever the acquisition time, possible evolution in lighting distribution and in system spectral sensitivity. Here, the chosen RGB space is related to the system: it can be obtained from system spectral sensitivity curves and lighting spectral distribution. The reference chart used for calibration is the Gretag MacBeth Color Chart DC (240 patches). Thus, we first need to know these patches' RGB theoretical values in our defined RGB space.

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2.1 Recovering Spectral Sensitivity

The first step consists in finding the most accurate spectral sensitivity curves of our acquisition system (channel R, G and B).
A classification of the most common methods can be given in two paradigms, indirect estimations and direct measurement methods which we will not detail here. Resulting curves are given for our acquisition system.

Many indirect estimation methods have been tested: by Pseudo-Inverse (Quan, 2003), by selecting principal eigen vectors (Hardeberg, 2000), by adding a smoothing constraint (Paulus, 2002), by mixing the two precedents methods (Paulus, 2002), and by combining basis functions, (Quan, 2003).

Another range of methods consists in finding sensitivity curves by direct determination (Vora and Farrell, 1997). We consider here camera responses to narrowband sampling of illumination.

In order to estimate sensitivity reconstruction validity and to select the one giving the most accurate results, errors in reconstruction have to be evaluated. This is achieved by estimating 540 patches P_E from computed sensitivity curves (2).

$$P_E=\sum_{\lambda}\left(S(\lambda)L(\lambda)\right) \qquad (2)$$

Various error computations are made, such as mean and maximum absolute and relative errors, standard deviation and RMS, for each channel and each of the recovered sensitivity curves.

A first analysis of computed errors leads us to select one method of estimation and one direct measurement method among all recovered curves. Comparing both leads to conclusion that, although methods are unconnected, error results are really closed. As carrying out an estimation method is faster, it will be kept rather than direct measurement. The selected method is the one using smoothing constraint. This curve is shown in Figure 1.

2.2 Theoretical Color Computation

From these sensitivity curves, theoretical patches can be computed (equation 3). They will stand as basis for color calibration. To get this theoretical set of RGB patches ($Patch_{Theo,k}$), a white balance $SysBal_k$ is applied.

$$Patch_{Theo,k}=\frac{\sum_{\lambda}\left(S_k(\lambda).L(\lambda)\right)}{SysBal_k} \qquad (3)$$

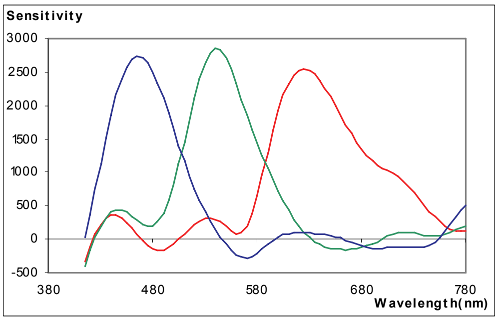

Figure 1 : Resulted Sensitivity curves estimation

It corrects system white deformation due to $S_{\lambda,k}$, while keeping the white relative to illuminant, chosen such that color can be well rendered.

3 CALIBRATION

To calibrate the system, three acquisition steps are required for correction. These corrections will also be applied to chart acquisition itself, to get correct mean values of acquired patches in order to calculate transformation.

3.1 Calibration Steps

First acquisition consists in recording a dark image. Let Im_{obs} be this image. Next acquisition, $Im_{Unif,k}$, intends to correct lighting and system acquisition non-uniformities (lens + RGB sensor), with a white chart. This double correction is applied with following equation (4), correction to which is added white balance (described previously):

$$\mathrm{Im}_{Cor,k}=Ratio_{Unif,k}*\frac{\mathrm{Im}_k-\mathrm{Im}_{obs}}{\mathrm{Im}_{Unif,k}-\mathrm{Im}_{obs}}*\frac{1}{SysBal_k} \qquad (4)$$

$Ratio_{Unif,k}$ is chosen in such a way that the RGB values of a pixel which coordinates correspond to a maximum value in uniformity image, remain the same.

The final calibration step consists in computing color transformation. It will make possible to change from acquired raw chart patches over theoretical patches. In practice, numerous transformation matrixes are computed for our calibration, corresponding to different integration times, determined from regularly sampling time range.

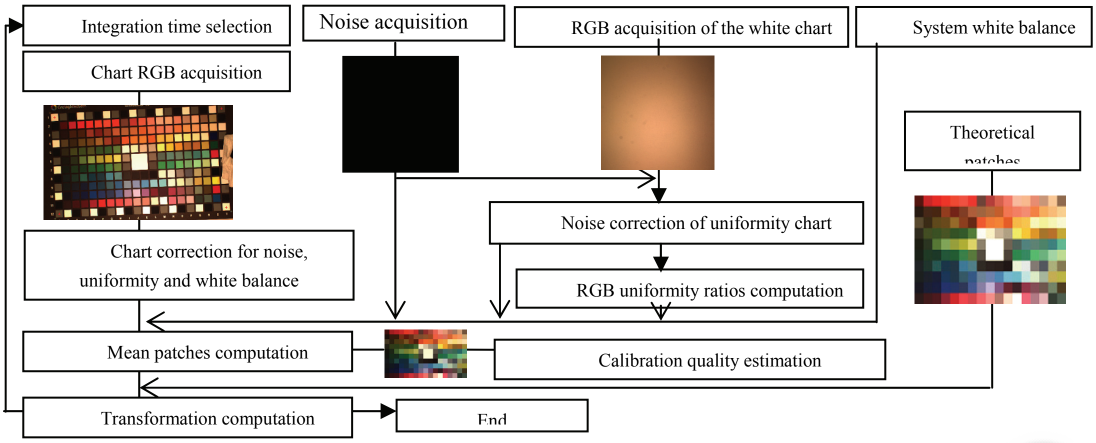

Figure 3 : Diagram of the different steps required to get RGB transformation for calibration

Once the chart acquired, it is corrected following equation (4). Then, only “linear” mean value of the patches set are kept for transformation computation: the three R, G and B values of these patches must stand in the sensor linearity range (above noise and below saturation knee). The number of kept patches is dependant of the considered integration time. All steps are summed up in Figure 3.

3.2 Transformation Computation

Let $Patch_{Acqui,k}$ the acquired patches set, for a chosen integration time. The transformation we obtained has been selected among various methods, adapted from Martin Solli’s methods (Solli, 2004). A linear regression has to be performed.

The simple and general transformation is given by equation (5):

$$Patch_{Theo} = g(Patch_{Acqui}) \tag{5}$$

An approximation of g-function can be expressed by the following expression (6):

$$g^*(Patchs_{Acqui}) = v^t a \tag{6}$$

with v the corresponding vectors of $Patch_{Acqui}$. (vector v is M functions $h_i(x)$ of $Patch_{Acqui}$). Vector a (M coefficients) which minimizes RMS difference between acquired and theoretical data, is given by the Moore Penrose pseudo-inverse resolution.

An important step then consists in choosing the right parameters in v vector. We have tested many of these parameters and the one we kept for our calibration, after a similar study on errors than previously, is the one called “combined order polynomial regression” (Orava, 2004).

3.3 Quality Measurement

As observed previously, for each integration time used for calibration, the number of kept patches varies. We need to know if some criteria of quality can be determined, in order to decide whether the set of patches are representative of the color space or not, and thus to validate calibration quality.

A first evaluation on patches is made on their repartition in the camera RGB cube. This repartition can be represented, as well as its projection on the three different RG, GB and RB plans. An example of it is given for two integration times, under a D65 lighting (figure 3). Same measurements have been done under a other illuminant (halogen lighting).

For low integration times, patches projection is concentrated in low values space: thus, this space is precisely sampled, but not very representative of the remainder of RGB cube. The more integration time grows, the more RGB cube is represented by patches (better under D65 lighting than under halogen lighting), but coarser the sampling is and lower the number of kept patches is (saturated patches increasing). Statistics on relative and absolute errors have been calculated, for various combinations of calibration and patches.

For each test, error evolution is the same. At low integration times, error is high. It then decreases down to a floor, value which is kept during an important integration time range. It finally significantly grows for higher integration times.

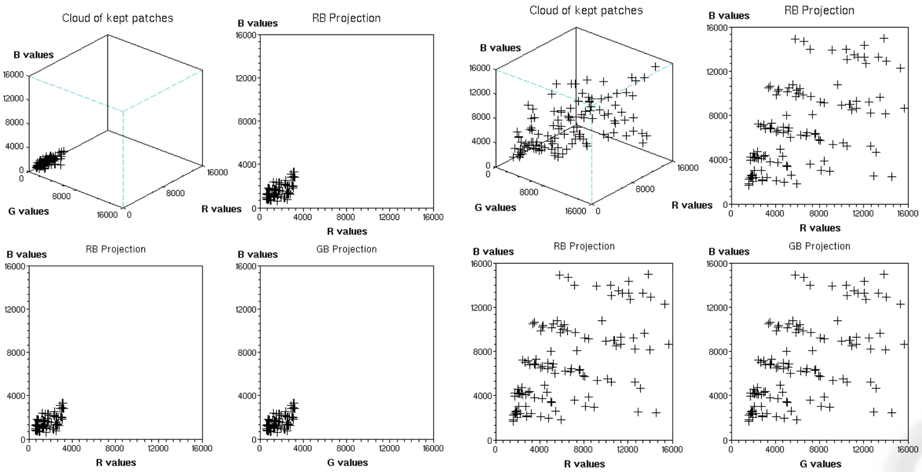

Figure 4 : Repartition of RGB patches in camera RGB cube, and on RG, RB, GB projection plans for integration time of 62.5ms (right) and 500ms(left).

Considering that an error variation above 200% of its lowest level, implies that this error is not acceptable, for calibration with 170 patches, whether being under D65 or under halogen illuminant, more than 50% of the whole patches set have to be kept in order to get R, G and B errors in this range.

The various results show that only considering a number of patches is not sufficient. Criterion of calibration quality also depends on lighting and chart. Only knowing these conditions allows such a criterion: for D65 lighting with a Gretag MacBeth Color DC chart, calibration gives little errors, if the number of kept patches, is higher than 50% of the 170 original patches.

Other aspects have to be taken into account: if integration time is low, when considering patches that are projected outside the restrained represented volume, committed errors are then very high, as those patches have not been taken into account when calibration matrix has been computed.

4 CONCLUSION

Once calibration data are computed, a raw acquisition of any object can be corrected and calibrated. Different steps are then required.

First a selection of the integration time is automatically done by dichotomy. Then, the calibration matrix corresponding to the nearest integration time using during calibration step is selected. Raw RGB acquisition is then accomplished. Calibration steps remain: correction for noise, for non-uniformity and for white balance following equation (4) is performed, then a linear transformation of the data is done (to make integration time used during acquisition and the one used during calibration correspond). Calibration matrix can next be applied, followed by the inverse linear transformation.

We have carried out a calibration method, with all required step, and tested quality of this calibration in function of integration time. Our final calibrated images show very good results. Further works could be applied on calibration quality.

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