Verification and extension of a camera-based end-user calibration method for projection displays

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Abstract

We evaluate, analyse and propose improvements to a previously published end-user calibration method for projection devices (Bala and Braun, CIC 2006). We focus on the estimation of the displays tone response curve, using only an uncalibrated consumercamera. The results show that the method is accurate, depending on both the projector and the camera used. We found that the method is accurate enough for most end-user applications. A weakness of this method is the wrong estimation of the projectors black level, which significantly affects the estimation of the camera response curve.

Introduction

Nowadays, projection displays are widely used but rarely calibrated properly [1]. The resulting lack of color accuracy often leads to not only a loss of visual appeal in the presented material, but also in many cases to a loss of intended meaning. Accurate colorimetric calibration of projection displays is technically challenging and requires expensive specialist equipment. Bala and Braun [2, 3] recently presented an alternative enduser method for projection display calibration. The work presented in this paper aims is to perform an independent evaluation and analysis of this method, and to propose and evaluate improvements.

Proposed methodology

The Bala method [2, 3] aims to achieve a good calibration for projection displays using no equipment other than an uncalibrated consumer digital camera that anyone could have at home. This removes the need for any radiometric or colorimetric measurements in the calibration process. It can be assumed that the system primaries are sRGB [5].

Their proposal is to calibrate the camera relatively to the display, using the following information:

(a) The 50% luminance point of the projector [2, 3, 4], estimated visually using a matching pattern.

(b) Considering the maximum luminance at 1 and the true black at 0.

(c) Considering the black level of the projector at 2% of the maximum luminance [2, 3] (for a dim surrounding).

This information is used to estimate the camera response curve, using spline interpolation. Based on this estimation, the camera can replace a more sophisticated photometric measurement device and can be used to estimate the projectors tone response curve, by taking a picture of a pattern displayed on the screen. We invite the reader to read [2, 3] in order to get all details.

In the present work, the Bala method is re-implemented with the aim of identifying strengths and weaknesses of the approach. Moreover, we propose to enhance the original method as follows:

(a) The original method assumes that the normalized grey level response curve is the same as the normalized curves for each primary. We propose to separate estimations of the three primary color channels response curves through duplication of the calibration procedure per channel.

(b) Another improvement is to increase the number of visually determined luminance levels from one to three by adding targets for 25% and 75% luminance to the original 50% level, obtained by a haltoning like process, similarly to the full visual calibration proposed in [6].

Experimental setup and results

The Bala method and its proposed enhancements were implemented and tested with two different digital cameras: the Nikon D200 DSLR and the Fujifilm Finepix S7000 compact type camera, and two different projectors with different technologies: a Panasonic AX-PT100E LCD and a Projectiondesign Action one DLP. All experiments were done with default hardware settings and no gamma correction performed by image source computer.

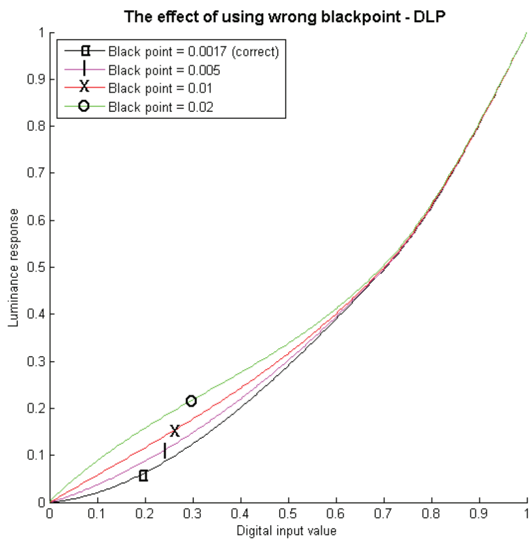

Figure 1. Camera response estimation using different black levels. Giving a wrong black point makes the estimation to vary strongly for the luminance below the 50% of the projector.

Throughout our experimentation with the Bala method [7] it became apparent that the method can be accurate enough for some applications, but performances are largely dependant on three main factors:

(a) The estimation of the cameras response curve is based on four points. Two of these are the absolute black point and the projectors black point which are close together. The proximity

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Table 1: **Average ΔL^* between the real projector response curve and the estimated one (the 256 possible values were measured and estimated), depending on the method used.**

Method	Projector	ΔL^*	ΔL^* Red	ΔL^* Green	ΔL^* Blue	RGB average ΔL^*
Original	LCD	3.47	-	-	-	-
3 matched luminances	LCD	2.14	-	-	-	-
Original	DLP	1.64	-	-	-	-
3 matched luminances	DLP	0.59	-	-	-	-
Separate Channel match w/ 1 lum. match	LCD	-	1.83	3.03	2.51	2.46
Separate Channel match w/ 3 lum. match	LCD	-	1.48	2.30	1.92	1.90
Separate Channel match w/ 1 lum. match	DLP	-	1.90	1.05	2.96	1.97
Separate Channel match w/ 3 lum. match	DLP	-	1.89	0.96	2.01	1.62

of these points strongly influences the shape of the interpolation function. We have concluded that the projectors black level needs to be measured or estimated with good accuracy when using this method (see Figure 1). We propose no solution for an estimation of this parameter without an accurate measurement device. This is a major weakness in the approach as it moves away from the initial chain of thought on replacing expensive color and luminance measurement equipment with the digital camera. We do not put aside the fact that for other interpolation methods it could work well with a generic black level. However, we wonder how increasing the number of visual pattern (in low luminances) while simply removing the projector black point to estimate the camera response curve can achieve good result. (b) Secondly, the observers precision in the visual matching task will determine a third point in the interpolation of the camera response curve. This will have significant influence on the estimation of camera tone response. This is the weakness of every visual calibration method. Note that the visual estimation of the 50% luminance for the blue channel is a harder task for the human visual system compared to the higher wavelengths of red and green. Furthermore, a "grey balancing" [8] method can not be used as the projectors are used to show a large chromaticity shift with the variation of input for the pure primaries.

(c) The third factor is the cameras capability to differentiate between projected luminances in the calibration pattern. If it lacks accuracy when recreating on-screen luminance differences it will not give the information needed to estimate projector tone response. When testing the method it became clear that the FujiFilm camera had severe problems with capturing suitable images for use with this method. The captured images seemed to be either saturated in brighter areas or the darker patches were indistinguishable from each other, and the resulting estimated curves were not good. Major efforts were put into experimentation with camera settings without achieving better images. As a consequence, the camera was not found suitable to be used with this method; hence no further results from this camera will be reported.

Although such critical factors were identified, the method shows good results (Table 1). These results are presented for a dark surrounding. The ΔL^* is computed from the measured response curve and the estimated one, for a full ramp (256 values) of grey level patches or for each independent channel. Note that Bala et al worked in dim surrounding. In such a case, it is possible that the estimation of 2% luminance for the black level is better. To be fair in our comparison, and to present comparable results, all the methods presented used the same level of black, which is the black level of the projector measured with a spectroradiometer Minolta CS-1000. The ΔL^* has been computed for two luminances L_1 and L_2 as $\Delta L^* = \sqrt{(L_1 - L_2)^2}$.

Figure 2 shows the estimated tone reproduction curve for the Projectiondesign DLP projector using the original method. Here an average ΔL^* luminance difference of 1.64 from the projectors measured response was achieved. Figure 3 shows results when using the extended method with three visually matched luminance levels instead of one. This shows an even closer match to the measured response with an averaged ΔL^* difference of only 0.59. With the LCD projection device, we obtained 3.47 ΔL^* for the original method to 1.90 using both improvements (calibration of each primary, with 3 visual patches). The Figures

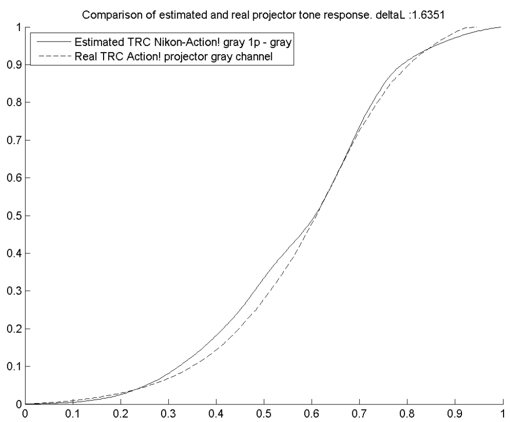

Figure 2. Normalized luminance grey level response curve estimation for the original method (plain line) versus the measured one (dashed line) for the DLP projector, function of the input digital value.

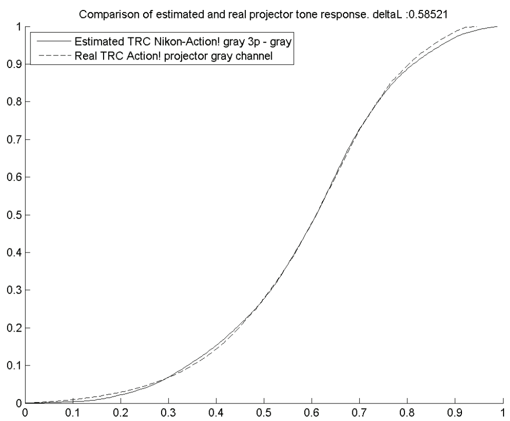

Figure 3. Normalized luminance grey level response curve estimation for the three luminance matchs method (plain line) versus the measured one (dashed line) for the DLP projector, function of the input digital value.

4 and 5 are showing the estimated tone response curve for the LCD for respectively the original and the extended method using three visually matched luminance levels. One can notice the same thing that for the previous display: we reduced the average error to 2.14.

It appears that the independent estimation of the blue channel response curve for the both projectors show a ΔL^* of 2.52 and 2.96 for one luminance match and of 1.92 and 2.01 for three luminance match. It is supposed to be the worth case as the visual system is not good to distinguish luminance changing in the short wavelength. Using three luminance matching points, we improve the estimation of the blue channel response curve, while for the red channel, this does not change the result very much. Doing this for the DLP projector green channel, we do not improve the estimation quality. However, the LCD projector shows a large error of matching for this channel, and using three points is beneficial for its estimation. Note that this error in matching luminance for the green channel, over the error on the blue one, appears strange for us. It is possible that the bad match in luminance is induced by a strong chromaticity shift on the green channel.

When using an inverse characterization model, in the case of

Table 2: ΔL^* for different methods for an inverse model test built up on a set of 16 greyscale luminance patches.

Method	Device	Mean ΔL^*	Max ΔL^*	std. dev.
Original (Bala)	DLP	2.30	6.21	2.00
3 matched luminances (using halftoned patches)	DLP	0.60	1.39	0.50
Separate Channel match w/ 1 lum. match	DLP	0.90	2.77	0.82
Separate Channel match w/ 3 lum. match	DLP	0.87	1.78	0.65
Gamma 2.2	DLP	10.53	25.68	9.52
Original (Bala)	LCD	4.13	9.14	3.02
3 matched luminances (using halftoned patches)	LCD	3.35	5.70	1.82
Separate Channel match w/ 1 lum. match	LCD	3.11	6.21	2.10
Separate Channel match w/ 3 lum. match	LCD	3.04	5.68	1.85
Gamma 2.2	LCD	4.32	9.31	3.03

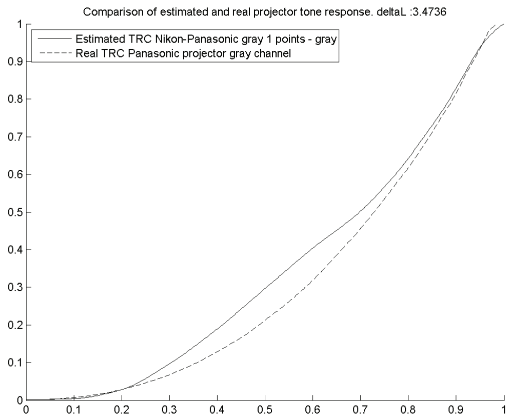

Figure 4. Normalized luminance grey level response curve estimation for the original method (plain line) versus the measured one (dashed line) for the LCD projector, function of the input digital value.

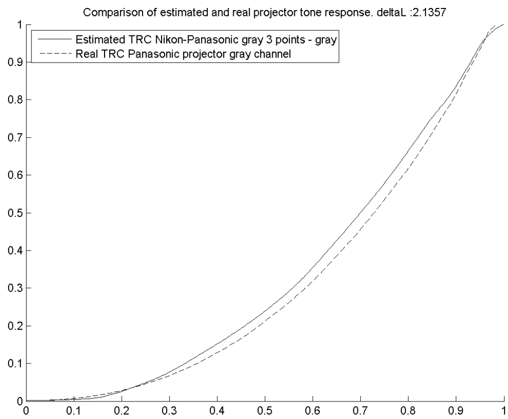

Figure 5. Normalized luminance grey level response curve estimation for the three luminance matchs method (plain line) versus the measured one (dashed line) for the LCD projector, function of the input digital value.

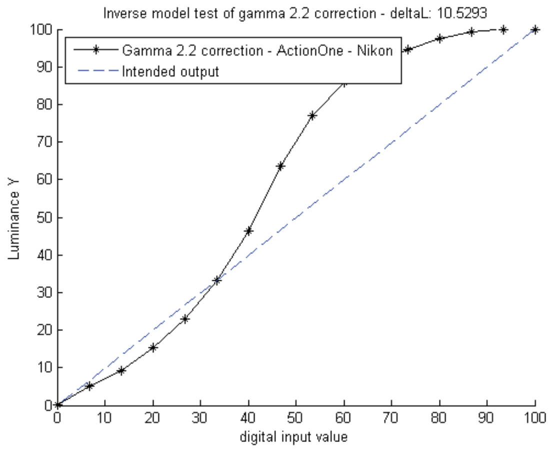

Figure 6. "Linearized" values using a 2.2 gamma inverse model. The dashed line is the ideal line.

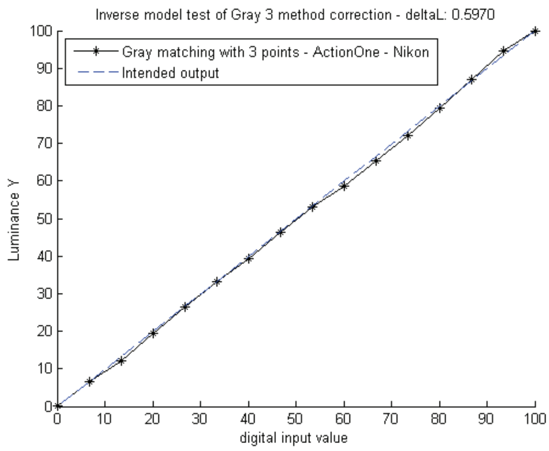

Figure 7. "Linearized" values using an enhanced Bala's inverse model. The dashed line is the ideal line.

color reproduction, the results from the forward model are confirmed. Table 2 shows numeric results for the inverse test with our two projectors. This table also shows results obtained when using the standard PC gamma correction of 2.2. We used a 16 greyscale set of patches. Here we can see that the widely used default gamma correction does not give satisfactory results when comparing to the proposed methods. Figures 6 and 7 show plots of corrected output respectively according to a standard 2.2 gamma correction and to the enhanced Bala method. It is obvious that for this display the 2.2 gamma correction is not working efficiently. However, the Bala's method achieve a good result.

Figure 8. *images used to confirm a better reproduction. the left image shows a good contrast range, a lot of details, a monotone background and skin tones. the middle one shows a high contrast and light color tones, the right one shows more color content and some high contrasted areas, as the beaks.*

Additionally to the inverse test, we performed psychovisual experiments using three ISO sRGB images (Figure 8) and ten observers. We applied a correction to each image using the luminance response curves retrieved with each method, and the observers visually evaluated the methods through on-screen pair comparison between all methods. On Figures 9 and 10, one can see the result of the experiment using the LCD projector and the DLP projector. The result of this experiment doesn't show any significantly better correction for the LCD projector, at least no confidence interval let show a definitive better way. Even the RGB 1 in Figure 9 is worse than the other, probably due to the bad estimation of the green channel response curve (table 1). The similar results for each correction are due to the shape of the projector tone response curve which fits better than the DLP projector with a 2.2 gamma (Figures 4 and 5). Moreover the estimation of this curve is less accurate than for the DLP projector. For the DLP projector, as we can see on Figure 2 and 3, the shape of the curve does not fit a gamma curve, thus we can clearly see that the gamma correction do not work on Figure 10. Moreover, it appears that the method which uses channel independent response curves estimation are giving better results than the one which are using the grey level response.

Conclusion

We have verified that the model proposed by Bala yields significantly better color reproduction than using default gamma settings for both the LCD and DLP projectors. It is a quick and simple approach, which does not require any accurate measurement device. The proposed extensions add little complexity, yet provide a good improvement of the results. We would prefer to add more matching patterns rather than to calibrate each channel independently, at least as long as the normalized response curves are similar by channel -which is not obvious for LCD-, because of the rate time/accuracy won. We still have to find a good solution to perform a better estimation of the projectors black level in order to permit the model to give its best.

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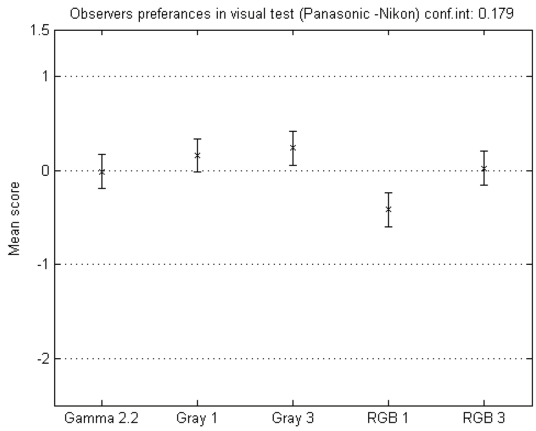

Figure 9. *Psychovisual experiment results for 3 images. The 10 observers were asked to choose the best correction of two simultaneously displayed corrected images for all the possible combinations of five different methods, including the gamma 2.2, one (Grey 1) and three (Grey 3) luminance matching on the grey ramp, and one (RGB 1) and three (RGB 3) luminance matching on each ramp, on the LCD projector. The higher the value is, the better the correction is relatively to the others.*

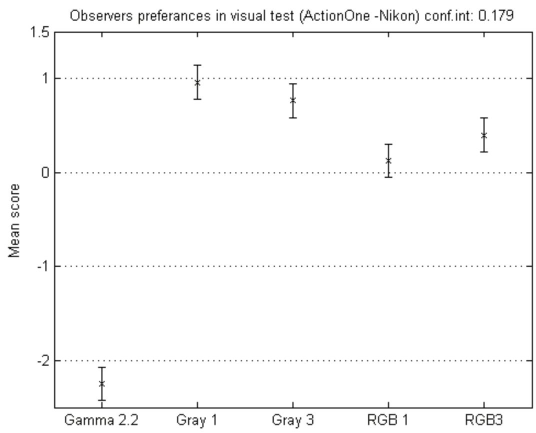

Figure 10. *Psychovisual experiment results for 3 images. The 10 observers were asked to choose the best correction of two simultaneously displayed corrected images for all the possible combinations of five different methods, including the gamma 2.2, one (Grey 1) and three (Grey 3) luminance matching on the grey ramp, and one (RGB 1) and three (RGB 3) luminance matching on each ramp, on the DLP projector. The higher the value is, the better the correction is relatively to the others.*

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