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ASSESSING RGB DEVICE CALIBRATION CONTROL LEVEL

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Colour reproduction devices are calibrated with the aim of maximizing their performance and setting them in a known state. Many calibration methods have been developed for colour reproduction devices which provide direct control over their colorants' amounts (CMYK devices). Devices with no direct control over their colorants' amounts are normally not calibrated and are therefore less accurate regarding the colour reproduction. This paper investigates the possibilities of calibrating such devices, i.e. the level of control that can be established over them. For that purpose, basic principles of the existing calibration methods were taken, but the method of determining the aimed values was modified and extended with novelties. The evaluation showed that this attempt did result in some improvements, however, should be studied more carefully as it was revealed that the process was uncontrolled in some aspects.

Keywords: *calibration, characterization, colour reproduction device*

Ocjenjivanje razine kontrole pri kalibraciji RGB uređaja

Izvorni znanstveni članak
Grafički reprodukcijski uređaji kalibriraju se s ciljem poboljšanja performansi i dovođenja u poznato stanje. Postoji mnogo metoda razvijenih za reprodukcijske uređaje koji pružaju izravnu kontrolu nad svojim bojilima (CMYK). Uređaji bez izravne kontrole nad svojim bojilima ne kalibriraju se te stoga pružaju manju točnost u pogledu reprodukcije boja. U ovome radu istražene su mogućnosti kalibracije takvih uređaja, to jest razina kontrole koju je nad njima moguće uspostaviti. Za tu su svrhu preuzeti principi postojećih metoda kalibracije, a metoda određivanja ciljanih vrijednosti je modificirana i proširena. Evaluacijom je utvrđeno da su postignuta poboljšanja u odnosu na nekalibrirani uređaj, ali i da je potrebno dodatno istraživanje s obzirom da se proces pokazao nekontroliranim u nekim aspektima.

Ključne riječi: *kalibracija, karakterizacija, reprodukcijski uređaj*

1 Introduction

Colour reproduction device calibration has several objectives. One of them is bringing the device in a state in which it behaves optimally with respect to its reproduction characteristics. This means achieving maximum dynamic range and maintaining as much contrast when compressing parts of a tonal range. Another objective is bringing the device to a known state in order to maintain repeatability. Every change of substrate or set of inks causes changes in device's characteristics [1]. In addition to calibration, devices are usually characterized. While calibration changes the device's behaviour, characterization describes it. It is a description of input-output relations in the form of a physical model, numerical model, or a look-up table [2]. Characterization serves the purpose of predicting the input (in CMYK or RGB colour space coordinates) needed to achieve a certain appearance of colour (in CIE $L^*a^*b^*$ colour space coordinates). Calibration is not a necessary prerequisite for characterization. However, it is known that calibration improves the precision of characterization. This particularly relates to device's gray balance. Devices which are not gray balanced, i.e. have a hue shift toward some region of a colour space are wasting much of the model's prediction power in that region, while the others, especially the complementary region are characterized poorly [3]. This paper investigates how some good practices established on CMYK devices apply to RGB devices. In addition, it modifies and extends the methods of obtaining the aim values and channel reproduction curves. Existing calibration methods differ in ways of obtaining correction values and in their aims regarding the tonal changes applied. All of them are based on obtaining the correction curves of device's input channels. In the experiment presented in this paper, principles of the G7 calibration method developed for CMYK devices were applied to the RGB printer. An RGB printer is a colour reproduction device for which its driver takes RGB values as inputs and converts them to CMYK ink amounts. The user has no direct control over the device's inks. The main objective of the G7 method is achieving the gray balance in the reproduction. The G7 Specification defines gray balance as a function of the substrate colour, which differs it from traditional definitions of gray. The objective of this approach is the maintenance of balanced visual appearance of gray tones with respect to the substrate colour. The G7 Specification also specifies sets of correction curves which are functions of the ink density range. Those functions were derived empirically, and their most important property is compressing the dark and preserving the light tones on devices with wide ink density ranges. On devices with smaller ranges, the compression is shifted towards lighter tones to the necessary extent. The functions with such properties were derived because the observer is more sensitive when it comes to noticing differences in light tones. However, these correction methods were developed for CMYK devices where each curve is directly related to the device's physical colorant amounts. Within this research, calibration methods were modified to adapt to RGB devices and applied to an RGB device in order to inspect whether they yield satisfactory results when there is no direct control over the ink amounts, i.e. when the relationship between inputs and outputs is more complex.

2 Materials and methods

The research was carried out on a desktop thermal ink-jet printer. The device's driver receives RGB input values and converts them to colorant amounts. The user has no way of controlling the colorant amounts directly. A test chart comprising different RGB input permutations was prepared. As it had to cover a range of hue shifts on different lightness levels, one channel was kept constant, and the other two varied. The R channel was chosen to be kept constant on the following values: 31, 63, 85, 127, 170 and 191. The G and B channels were varied as $R\pm9$ in steps of 3. That means that the central patches of each of the six patch groups of constant R are printed with equal RGB input values, and should ideally be neutral. The surrounding patches should exhibit increasing hue shifts as they get further from the central patch. The six groups of patches differ in lightness. Fig. 1 shows one of the six patches, where R is kept constant at value 63, and G and B are varied. The chart was printed on plain 90 g/m^2 paper and measured using a spectrophotometer with 45°/0° measuring geometry, under conditions D50 illumination and 2° observer. CIE *L*a*b** values were obtained.

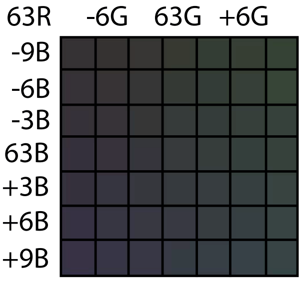

Figure 1 One of six groups of patches

As there exist different definitions of gray, one has to decide which one of them to adhere to when setting the calibration aim values. In this research, the G7 definition, specified in the G7 Specification was chosen. It defines gray relative to the colour of the substrate. In CIE *L*a*b** colour space, neutrals are achieved at 0*a** and 0*b** for any given *L** (lightness). As the substrate colour cannot be influenced, the G7 definition prescribes aim *a** and *b** values as functions of substrate colour, where they linearly converge from unprinted substrate towards zero as CMY inks amount increases toward maximum. In order to apply this principle on RGB values, opposite functional relationship was used as smaller RGB values represent darker tones.

Table 1 Aimed values and their corresponding predicted inputs

	Aim				Predicted		
R	*a**	*b**	*D*	*L**	R	G	B
0	0,00	0,00	1,50	21,00	0	0	0
31	0,40	−1,42	1,22	29,62	34	36	41
63	0,82	−2,89	0,95	34,18	53	53	58
85	1,01	−3,90	0,78	44,32	88	88	88
127	1,64	−5,83	0,54	56,49	126	125	124
170	2,20	−7,80	0,34	65,11	154	151	153
191	2,47	−8,76	0,25	78,80	202	200	201
255	3,30	−11,70	0,08	93,00	255	255	255

After the chart containing six groups of patches was printed and dried, *L*a*b** values of patches were measured. In addition to the patches, the unprinted substrate and full ink amount *L*a*b** and density *D* measurements were taken. The G7 NPDC curve was now used to determine aimed *D* values, and they were used to determine aimed *L** values (Tab. 1). Fig. 2 shows the known ten points of the curve interpolated with third order spline in order to obtain *D* values for RGB (Tab. 1) values *a** and *b** in Tab. 1 were obtained as linear functions of substrate colour, converging toward zero for full ink amount.

As at this point the aimed *L*a*b** values were known, their corresponding RGB inputs had to be predicted. For that purpose, the data of the six groups of patches were fitted with a third order regression model of the following form:

$$[L^*\ a^*\ b^*]=[1\ R\ G\ B\ RG\ RB\ GB\ R^2\ G^2\ B^2\ R^2G\ R^2B\ G^2B\ G^2R\ B^2R\ B^2G\ RGB\ R^3\ G^3\ B^3]A$$

where ***A*** is a coefficient matrix. The predicted RGB inputs are displayed in Tab. 1. The model's quality of fit was evaluated and expresses as CIE $\Delta E_{a^*b^*}$ (Euclidean distance in *L*a*b** colour space), and the results are displayed in Tab. 2. Since the model is used to predict values, its predictive power should be evaluated. This evaluation is usually done on the independent data set which reveals a higher amount of error [4]. Within this study, evaluation was performed on the training set as the domain is quite small (near-neutral tones) compared to usual modelling of the whole device space. The amounts of error are therefore very small, and as predictive power evaluation usually displays only slightly worse results, this can be considered quite acceptable. In addition to that, third order models do not tend to overfit the data and cause local minima and maxima as some higher order models.

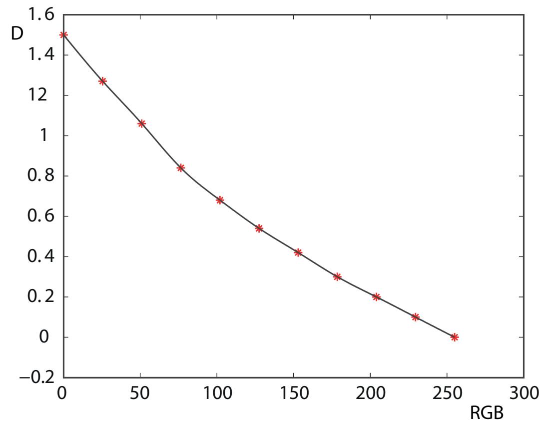

Figure 2 Aimed densities curve

Table 2 Model evaluation results

Model	Min ΔE	Mean ΔE	Median ΔE	Max ΔE
RGB→*L*a*b**	0,14	0,67	0,64	1,79

Fig. 3 shows the correction curve for the R channel obtained from the data displayed in Tab. 1. The points are the sets of initial RGB (R) values on abscissa and predicted correction R' values on the ordinate. Points were interpolated with a third order spline to produce a correction curve. Splines can be used to compute any of the intermediate values. The same method was applied to obtain G and B correction curves. Once the correction curves were obtained, they were applied to the test chart and a test image. The chart was measured (*L*a*b** and density values) and the image was evaluated psychophysically.

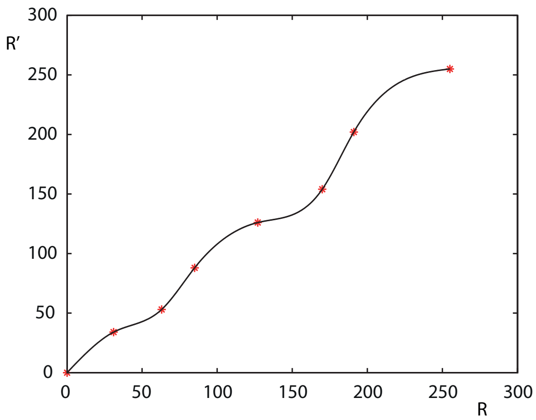

Figure 3 R channel correction curve

3 Results

Tab. 3 displays the aimed values and the values measured on the chart with corrected RGB curves. The measured inks densities were slightly higher than aimed on the whole scale except the maximum density which was slightly smaller. Ink densities were used to determine *L** aimed values. When the aimed and measured *L** values are compared, it can be noted that all of the measured *L** values are slightly higher than the aimed. It is interesting to note that on the highest density patch measured *D* value was smaller than aimed, and measured *L** value was higher than aimed. When the differences and extents of differences between measured and aimed values are compared for *D* and *L**, it can be noted that *D* is a fairly good, but not completely accurate approximator of *L**. Small differences in *L** are also caused by the model error.

Table 3 Aimed and measured values and their difference

Aim				Measured				Diff.
D	*L**	*a**	*b**	*D*	*L**	*a**	*b**	Δ*E*
1,22	29,62	0,40	–1,42	1,14	32,30	0,30	–2,10	2,766 731
0,95	34,18	0,82	–2,89	1,04	36,20	1,70	–4,90	2,982 432
0,78	44,32	1,01	–3,90	0,82	46,00	0,30	–4,60	1,953 586
0,54	56,49	1,64	–5,83	0,61	56,80	–0,10	–4,10	2,473 176
0,34	65,11	2,20	–7,80	0,45	66,20	0,20	–5,00	3,609 446
0,25	78,80	2,47	–8,76	0,26	79,40	2,40	–7,70	1,220 041

When comparing the aimed and measured *a** and *b** values, it can be noted that the highest and smallest map with fair accuracy. However, what happens in between is that they oscillate, changing in general trend, and not linearly as intended. This could have two reasons. One is the model accuracy, and the other is device repeatability which was not tested in this study. Considering the amount of error, most of it is likely to come from the model. However, when the colorimetric differences, ΔE between aimed and measured values are inspected, it is noticeable that these differences are quite small and are considered acceptable by standards and in common practice.

Fig. 4a shows the original, and Fig. 4b shows the corrected image. Although their appearance on the device used in this research cannot be faithfully reproduced, they can serve to illustrate tonal changes that took place.

Figure 4a Original image

Figure 4b Corrected image

The corrected image exhibited more contrast. Some details, not visible in the original image, became visible in the corrected image, but at some expenses. The first thing to note is that a range of light tones (sky in the image) was lost and reproduced much lighter. On the other hand, dark details (bridge construction), all reproduced very dark and invisible in the original image became visible in the corrected image. Although the appearance of fine details in dark tones could be considered as improvement, we must bear in mind that the aim was quite the opposite, i.e. preserving as much light tones and compressing the dark tones. The reason of this effect lies mostly in the nonlinear and nonmonotonic relationship between RGB inputs and device's colorants. When device calibration curves directly relate to physical colorant amounts, their corrections are usually monotonic over the whole tonal range. Values are either increased or decreased on the whole range. Since in this case there is a complex nonlinear relationship between the inputs and the device's colorants, the correction curves, as can be seen in Fig. 3, have several bends. The distribution of points was such that the correction curves (Fig. 3) were more linear in dark tones, and quite nonlinear in light tones, causing their loss. However, it must be taken into account that very important modification of methods adapted to CMYK devices was overlooked. The six groups of patches were distributed over a tonal range in a way that more points were placed in dark tones, i.e. their distribution was not inverted for RGB. The experiment, as the results suggest, should be carried out with test patches distributed oppositely over the tonal range.

Another difference between the original and the corrected image was noted in the appearance of gray tones over the range. As the tones get darker on the original image, they exhibit a yellow cast. This is expected, and one of the aims of the G7 approach to calibration is correcting such tonal casts, making the reproduction appear neutral over the tonal range, relative to the substrate colour. On the corrected image, this tonal cast was not visible and tones appeared neutral over the whole range. Therefore, despite the oscillating a^* and b^* values displayed in Tab. 3, the calibration was successful in this aspect. Even the amounts of ΔE error displayed in Tab. 3 are normally considered quite small and acceptable.

4 Future work

The most problematic aspect of the applied method is that it caused compression in the opposite end of the tonal range than expected. The main reason for this was, despite applying the corrections validly, in the improper distribution of the points to which the corrections were applied. In order to adapt the method to RGB devices, patch groups would have to be distributed oppositely throughout the range, ensuring more points in the light tones. This would also make the corrections more monotonic as fewer points would be placed in dark tones, compression of which is resulting in higher curvature.

Another problem, although less expressed in the corrected image, was the prediction of RGB inputs needed to achieve achromatic tones, i.e. gray balance over the range. The problem is, as stated previously, mostly caused by the model accuracy. In this experiment, a third order polynomial model was fit to the dataset of six groups of patches, 6 × 49. The domain was relatively small as the hue ranges were small, but the lightness range was quite wide. The authors believe that much more accurate predictions could be achieved with local models, i.e. separate model fit to each of the six groups of patches. This would make the lightness range of the model domain much smaller and result in overall greater accuracy. Some modifications of local models result in dramatic accuracy improvements [5]. This, however, would require a larger test chart as 49 points within a patch group would not suffice, and the matrix system would be underdetermined. Possible improvement could also be a chart with all of the three channels varying as this would provide more training values of R channel (kept constant here) and therefore more accurate approximation of R channel. Further improvement would result in creating a chart with values of central patches determined after application of NPDC curve. This would mean printing only central R=G=B patches, determining their L^* and D^*, determining aim L^* and D by NPDC curve, and then creating a test chart with central patches shifted to the aimed values. This could significantly improve the model accuracy.

5 Conclusions

The calibration method presented in this paper successfully fulfilled one of its aims, gray balancing and elimination of tonal cast in darker gray tones. On the other hand, it completely failed in another important aspect, preserving light tones at the expense of the dark. However, it should be taken into account that the method was based on the existing method developed for the calibration of CMYK devices, and was modified only partly. The results of this experiment revealed sources of problems, and possible solutions described in previous section should be investigated more thoroughly.

6 References

[1] Fraser, B. et al. Real World Color Management, Peachpit Press, Berkeley, 2005.
[2] Sharma, G. Digital Color Imaging Handbook, CRC Press, Boca Raton, 2003.
[3] The G7 Specification 2008, IdeAlliance, 2008.
[4] Green, P.; MacDonald, L. Colour Engineering, Wiley, Chichester, 2002.
[5] Monga, V.; Bala, R. Shaped Local Regression and its Application to Color Transforms, Proceedings of Seventeenth Color Imaging Conference, Albaquerque, November 2009, pp. 272-277.

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