Development of accurate electronic colour communication

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ABSTRACT

Colour communication based on CIELAB and spectral data is often inaccurate due to poor inter-instrument agreement and lack of standardisation. Based on NCS[1], an accurate method intended for industrial colour communication, similar to the ICC profiles[2], is proposed. The performance and accuracy of the method for some portable spectrophotometers are investigated.

1. INTRODUCTION

Accurate colour communication between producers and buyers is important. Good colour match increases the quality impression of a product, lowers costs and saves time. Today, a physical standard from the customer is used by the producer for instrumental checks of the delivered products. This process demands good *repeatability* and *reproducibility* from the instruments, *inter-instrument agreement* and *accuracy* are of less importance[3]. For accurate electronic colour communication, the later criteria are the most important ones.

The *intra-instrument agreement*[3] is specified only for instruments of the same model and is often within 0.15 ΔE^*_{ab} on the 12 BCRA Series II ceramic standards[4]. No matt or textured surface is used and no specification is given of the *accuracy*. Colour differences around one ΔE^*_{ab}, measured in different models (d/8, SCI), can be expected to wary up to ±0.55 units[5] in ΔE^*_{ab} and the uncertainty of standardizing laboratories[3] in reflectance values of white calibration is more than ±0.35%.

This method uses a Spectral Connection Space (NCS-SCS) in analogy with the ICC-profiles. A correlation module for each instrument is needed to transfer data to or from NCS-SCS. Calibrated NCS colour samples are used to create these modules.

Spectral data can then be transferred into the accurate NCS-SCS to be compared to the NCS Primary Standard spectral curves. These spectral curves can also be used for output from the NCS-SCS into the instrument's "device-dependent" space for accurate colour matching (see Figure 1).

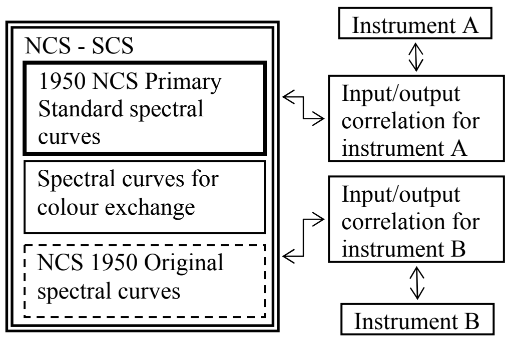

Figure 1. The NCS spectral connection space

2. INSTRUMENT CORRELATION METHOD

Variations in measurement result come from many different sources. The difference between the 45/0 and the d/8 geometries is the largest, and these values can not normally be compared. This method works accurately only for the d/8(SCI) geometry but one instrument with 45/0 geometry is included in this investigation for comparison. The variation between instruments with d/8 geometry is caused by systematic and random errors[6]. The accuracy of the colour coordinates is also influenced by the interpolation method and weighting table used. In this investigation, one instrument uses 10 nm data and ASTM table 6[7]. Using the spectral data, Lagrange interpolation and CIE weighting tables[8], an average of 0.12 ΔE^*_{ab} difference is found between the data for the 56 colour samples in Figure 2. By this reason, only spectral data is used, interpolated and extrapolated to be 380…5…780 nm data and all colour coordinates are calculated using the CIE tables.

The used correlation model is based on functions that model the systematic errors as described by R Berns and K Petersen[6]. The wavelength-dependent linear system of these functions is adjusted by linear regression.

For the constant wavelength step of $\Delta\lambda$ = 5nm the following function is used to calculate the reflectance difference:

$$\Delta R_C = a_0 + a_1 R_\lambda + a_2 (100 - R_\lambda) R_\lambda + a_3 \frac{(R_{\lambda+1} - R_{\lambda-1})}{2\Delta\lambda} + a_4 \frac{(R_{\lambda+1} - 2R_\lambda + R_{\lambda-1})}{\Delta\lambda^2}$$

The parameter a_0 represents the photometric offset, a_1 is the linear, and a_2 is the nonlinear photometric scale error, a_3 is the linear wavelength error and a_4 is the bandwidth error. These parameters are calculated for each wavelength, λ. To allow for both the input and output of spectral data to NCS-SCS, the reverse function must be available. That is done by calculating the same set of parameters with the measurement data exchanged with the calibrated data. Due to the different spectral range of the tested instruments, only wavelengths between 400 nm and 695 nm are used for correlation. The spectral data is then extrapolated to 380-780 nm.

Measurement data from a Macbeth ColorEye 7000 is used as reference. This instrument is correlated to the NCS reference Instrument, Zeiss DMC26. Both instruments are located at the Scandinavian Colour Institute in Stockholm. Figure 2 shows the spectral curves of the correlation samples measured in the ColorEye 7000. These are 56 NCS colour samples, selected to cover the colour space and give a reasonable distribution of different slopes over the spectral range of interest.

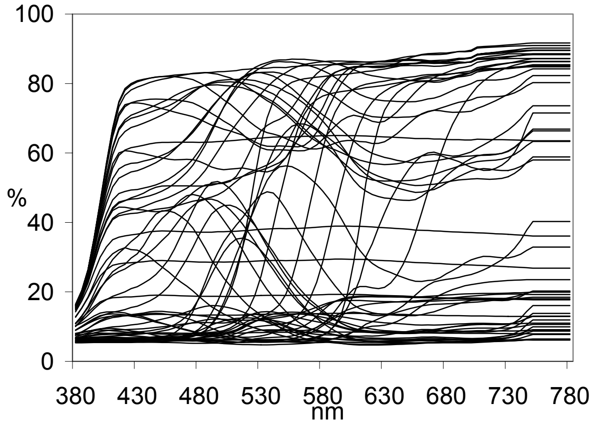

Figure 2. 56 spectral curves used for the correlation.

All measurements are done with the SCI. All ΔE-values in this investigation are CIELAB ΔE^*_{ab} values for comparison with most instrument specifications, the use of CMC or CIEDE2000 is however recommended due to their better conformance with visual observations.

3. CORRELATION RESULTS

The following instruments were used for this test (two different CM-2500d were available); ColorEye XTH from GretagMacbeth, Mercury from Datacolor, CM-2500d (1) and (2) from Konica-Minolta and DTP22 (45/0) from X-Rite. Figure 3 shows the normalized plot of the correlation parameters for CM-2500d (1).

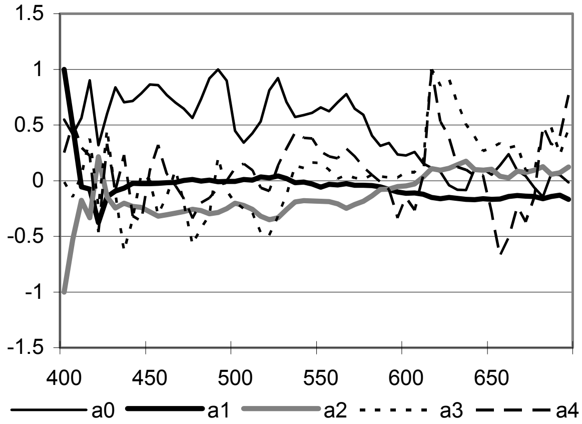

Figure 3. CM-2500d (1)

Due to the pigment used in the correlation samples, the reflectance in the short-wavelength area decreases quickly below 410 nm. That may be the cause of the oscillating behaviour seen in the parameter plots below 420 nm. The plots for the two CM-2500d show a good qualitative agreement compared to other instrument models. That clearly indicates that the correlation model finds the systematic errors and that random errors have little influence on the result. A characteristic shape of parameter a_4 in the range 620-680 nm is visible for all instruments and is probably caused by the Zeiss DMC26 monochromator, as already pointed out by Berns and Petersen[6].

Table 1 shows the average decreases in the difference between the ColorEye 7000 and the other instruments. Because these samples are the ones used to calculate the correlation, good performance is expected (except for the 45/0 geometry). The two CM-2500d stand out as the ones in the best original agreement with the ColorEye 7000 and are also reaching the best performance after correlation. The DTP-22 also shows large improvement but is still far away. That depends on the bad modelling of 45/0 geometry and the lack of gloss-dependent correlation.

	Average before		Average after	
	ΔE^*_{ab}	$\lvert\Delta R\%\rvert$	ΔE^*_{ab}	$\lvert\Delta R\%\rvert$
ColorEye XTH	0.97	0.45	0.47	0.20
Mercury	0.68	0.67	0.16	0.10
CM-2500d (1)	0.35	0.25	0.10	0.05
CM-2500d (2)	0.42	0.28	0.13	0.06
DTP-22 (45/0)	8.40	2.20	2.81	0.64

Table 1. Correlation result to ColorEye 7000.

4. CORRELATION PERFORMANCES FOR DIFFERENT GLOSS LEVELS

To evaluate the performance of the NCS-SCS method, a set of 42 NCS colour samples were selected, evenly spread in the colour space (seven of these are the same colours as the correlation samples). Each colour sample was divided into four parts, coated with transparent nitrocellulose lacquer of different gloss levels. The four gloss level is approximately 1, 17, 49 and 89 units. The gloss levels were all measured at an angle of 60 degrees. That gave totally 168 different surfaces. For each colour, the measured reflectance of the gloss levels 17, 49 and 89 are roughly the same in d/8 geometry. For the colours of gloss level 1 the reflectance is normally much lower. In the 45/0 geometry the reflectance shows a more linear behaviour to the gloss level.

All samples were measured in ColorEye 7000, this data was regarded as "true" spectral values. Thereafter samples were measured in the tested instruments and the "input" correlation was applied to all spectral data. Comparing the correlated data to the "true" data gave the results shown in Table 2. All instruments lose accuracy compared to the correlation samples. This loss depends mostly on the gloss differences but random errors are probably also influencing the result.

	Average before		Average after	
	ΔE^*_{ab}	$\lvert\Delta R\%\rvert$	ΔE^*_{ab}	$\lvert\Delta R\%\rvert$
ColorEye XTH	1.16	0.52	0.52	0.25
Mercury	0.57	0.27	0.34	0.29
CM-2500d (1)	0.33	0.26	0.33	0.19
CM-2500d (2)	0.58	0.34	0.30	0.16
X-Rite DTP-22 (45/0)	6.45	2.01	2.22	1.07

Table 2. Average increase in accuracy before and after correlation to ColorEye 7000.

To study the effect of gloss differences on the correlation, the result was divided into the four gloss levels. Table 3 shows the average decreases in ΔE^*_{ab} compared to the ColorEye 7000 and Table 4 shows the average ΔR%. The performance is increasing for all gloss levels except the lowest. That agrees well with the observed gloss-dependent differences in spectral reflectance for the d/8 geometry. This gloss-dependency is more evident for the 45/0 geometry, performing quite well for gloss levels of 17 and higher, but accuracy decreases ten times for the lowest gloss level.

	Before correlation				After correlation			
Gloss	**~ 1**	**~ 17**	**~ 50**	**~ 90**	**~ 1**	**~ 17**	**~ 50**	**~ 90**
ColorEye XTH	1.16	1.48	1.20	0.78	0.57	0.54	0.44	0.50
Mercury	0.25	0.46	0.49	0.52	0.52	0.25	0.20	0.19
CM-2500d (1)	0.33	0.32	0.33	0.34	0.42	0.27	0.32	0.30
CM-2500d (2)	0.57	0.58	0.60	0.58	0.39	0.24	0.29	0.27
X-Rite DTP-22 (45/0)	0.63	7.26	8.84	9.07	5.54	0.73	1.28	1.35

Table 3. $\overline{\Delta E^*_{ab}}$ before and after correlation for each gloss level.

Gloss	Before correlation ~ 1	~ 17	~ 50	~ 90	After correlation ~ 1	~ 17	~ 50	~ 90
ColorEye XTH	0.55	0.61	0.53	0.40	0.27	0.29	0.23	0.21
Mercury	0.25	0.46	0.49	0.52	0.52	0.25	0.20	0.19
CM-2500d (1)	0.21	0.22	0.28	0.31	0.27	0.16	0.17	0.15
CM-2500d (2)	0.27	0.33	0.38	0.38	0.22	0.12	0.17	0.15
X-Rite DTP-22 (45/0)	0.62	2.18	2.63	2.61	2.24	0.42	0.82	0.80

Table 4. $|\Delta R\%|$ before and after correlation for each gloss level.

For colour matching, the NCS Primary Standards must be transferred from NCS-SCS to the "device-dependent" colour space of the users own instrument. Using the ColorEye 7000 spectral data and the reverse correlation function gives almost exactly the same figures as shown in Table 3 and Table 4 when comparing the results.

5. DISCUSSION

Mathematical correlation of colour measurement data, to calculate accurate NCS-coordinates and colour differences, has been used successfully by the Scandinavian Colour Institute for more than ten years. Customers' demands for more accurate ways to match NCS 1950 Original Colours have resulted in an ICC-profile type, "Spectral Connection Space". The NCS Primary Standard spectral curves, available in the NCS-SCS, can be converted by these methods to the producer's own "device-dependent" colour space, defined by the measurement instrument they use. That will reduce the need of communication with physical standards and allow for more accurate electronic colour communication. Gloss level must be included in the correlation and random errors must be carefully controlled to reach the highest accuracy.

In the NCS colour language, any colour can be notated and described by NCS. The NCS-SCS can provide an accurate way to communicate any NCS notation (not only the 1950 Original Colour Samples). A method to calculate accurate spectral curves for any NCS notation, with low metamerism compared to the original 1950 NCS Primary Standards, in the NCS-SCS will provide this possibility.

Another possible extension is to include the possibility to use 45/0 geometry. These investigations indicate that a gloss-dependent correlation can give acceptable accuracy for many applications. An accurate measurement value for the gloss level of the surface must then be available and correlation modules for at least two gloss levels must be used.

References

1. A Hård, L Sivik, G Tonnquist, "NCS, natural color system - From concept to research and applications. Part II", Color Res. And Appl., 3, 206-220 (1996)
2. International Color Consortium, "Specification ICC.1:2004-10 (Profile version 4.2.0.0)", www.color.org (2004).
3. D Rich, "Standardized Terminology and Procedures for Specifying and Verifying the Performance of Spectrocolorimeters", AIC Color 97, Kyoto, 395-398 (1997).
4. R Hirschler and J Gay, "Industrial Colour Measurement – the State of The Art", Proceedings of SPIE Vol. 4421, 773-776 (2002)
5. A Raggi and G Barbiroli, Colour difference measurement: The Sensitivity of Various Instruments Compared, Color Res. Appl. 1, 11-27 (1993).
6. Roy S. Berns and Kelvin H. Petersen, Empirical Modelling of Systematic Spectrophotometric Errors, Color Res. Appl. 4, 243-256 (1988).
7. ASTM, "E308 Standard Practice for Computing the Colors of Objects by Using the CIE System", ASTM Standards on Color and Appearance measurements, 5ed (1996).
8. Colorimetry, 3rd ed. CIE Publication 15.2 Central Bureau of the CIE, Vienna (2004).