High-precision color communication for paper making between graphics arts and paper industry

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Abstract

This paper explores some influences on measurement results and means to tighten achievable tolerances. A set of unprinted paper samples including IR3 reference calibration standards was prepared and measured with 5 benchtop instruments (Elrepho-like) and 7 hand-held instruments (X-Rite Spectrolino). The samples were selected by surface (uncoated, matte, semimatte, glossy, high glossy) and effect of optical brighteners (OBA, from very low to high fluorescence).

The instruments were tested first for their short-term repeatability, then for inter-instrument agreement, which was better for the Elrephos, but could be matched for the Spectrolinos by adjusting for gloss and OBA response. Sample inhomogeneity required multiple Spectrolino measurements to match the Elrepho's XLAV aperture. With these methods and some precautions in calibration, measurements can be translated from one type of instrument to another with tolerances well below 1 ΔE.

Introduction

In the making of proofing papers for the graphics arts, CIELAB aim values and tolerances must be communicated. The customer uses hand-held instruments with small aperture and bidirectional geometry (45a:0°), and a meaningful specification for color management purposes uses CIELAB (D50/2°). The paper manufacturer uses UV-calibrated benchtop instruments with hemispherical geometry (d:0°) and CIELAB (D65/10°) for process control. The customer must first translate his specification, and secondly needs some means to check the delivered proofing paper for conformance within tight, but reasonable tolerances.

This paper deals with the question of what can be done to achieve smallest tolerances (here always stated as CIELAB ΔE 1976). Is it necessary to use the same kind of equipment as the paper manufacturer in order to verify production tolerances directly, or is it possible to use a proxy method which bridges the gap between worlds?

For color measurements, the choice of an instrument depends on many factors, like sample properties (flat or curved surfaces, textures, angular effects), or whether good visual correlates are needed or rather means for process control. The reported values, like spectral reflectances, reflectance factors, or colorimetric values, will usually capture some facet of surface reflection properties depending on the used technology and its focus. Therefore standards have been created for various industrial measurement tasks, like printed color in the graphic arts [1] and paper white in the paper industry [2], [3] (Table 1). Some differences are related to calculation methods and could be removed by using the same observer, illuminant, and bandwidth conditions for spectral data.

But even similar instrument types, governed by the same standard, will disagree to some extent due to differences in the geometries and apertures of illumination and detection, bandwidth of the spectral sensor, excitation of fluorescence, or simply in traceability; the latter meaning that the accuracy of reflection measurements itself is limited. [9]

Table 1. Selected international standards for spectral color measurements in graphic arts and paper industry.

	Graphic Arts ISO 13655:2009	Paper Industry ISO 2469:2007
Geometry	bidirectional 45°a:0° or 0°:45°	hemispherical d:0° but excluding gloss
Aperture	4 mm (typical)	28±3 mm detection 34±0.5 illumination
Backing	white backing (black: process control)	stack (= self-backing) (black: for opacity)
UV Conditions	M1 (equivalent to D50) M0 (UV uncontrolled)	D65 (outdoor daylight) C (indoor illumination)
UV-cut filter transmittance	<0.50 at 410 nm <0.10 at 400 nm	>0.50 at 420 nm <0.05 at 410 nm
Colorimetry & Spectral Weights [6]	CIELAB D50/2° bandpass-corrected	CIELAB D65/10° [4] CIELAB D50/2° [5] bandpass-uncorrected
Brightness	—	D65 [3]; C [7]
Whiteness	—	CIE W/T D65/10° [8]

So we have to examine precision and comparison of instruments. The higher an instrument's precision, i. e. its short- and long-term repeatability [10], the more we can depend on measured reference values and calibration procedures. Two different high-precision instruments may still disagree, but we can expect to create a good mapping between their results at least for specific samples. There are methods and products in use which attempt even a general "correction" from one instrument to another, typically reducing differences by a factor of 2–3.

Building on individual instruments can be dangerous: they can break, become misaligned, drift, or change due to factory recalibration. It is prudent to rely on a group of instruments of the same model, even if this introduces additional uncertainty by what manufacturers often call inter-instrument agreement [11]. Confidence can be further increased by monitoring instruments on stable references like ceramic tiles. Their long-term stability must of course be verified by the very same type of measurements — not really a chicken-and-egg problem as long as a variety of instruments are monitored (so that it is unlikely that all will exhibit the same drift, and they are effectively monitoring each other).

The Paper Industry World

In the paper industry world, brightness, whiteness, tint, gloss, and opacity are the color-related key words in the specification and process control of the paper shade [12]. Process control works best when these aspects are well separated. Therefore, it makes sense to use diffuse hemispherical illumination to measure color, and to measure gloss separately, also because a glossy or matt surface often depends on offline or online (super)calendering as last processing step before cutting. For a desired pulp or paper shade, brightness or whiteness is measured in the UV-calibrated mode, controlling dosage of optical brightening agents (OBAs) or of fluorescence-suppressing titan dioxide. The non-fluorescent mixture of paper dyes is better regulated by UV-excluded measurements.

The baseline calibration is done by IR3 standards: a non-fluorescent paper is used for spectral photometric calibration, a fluorescent one for UV calibration based on a whiteness or brightness target value. With a calibrated instrument, ceramic non-fluorescent and fluorescent working standards are characterized, typically in pairs. One is safely stored, the other is for daily use.

The Graphic Arts World

In the graphic arts world, color management is a central topic. It relies on the communication of color aim values across the production chain of design, prepress, and printing. The basic conditions are the CIE Illuminant D50 and the CIE 1931 2° Standard Observer. Ideally, measuring and viewing should use light sources that are close to D50 with respect to chromaticity, color constancy, metamerism, and excitation of OBAs. Since people tend to avoid specular gloss during visual inspection in order to increase contrast, color values from a bidirectional measurement geometry correlate better to what we see.

Tolerances apply to the accuracy of proofing and process control which are not far from the accuracy limits that can be certified by national institutes based on error estimates and propagation [13]. It is common that the inter-model differences between manufacturers can be larger than half of the allowed tolerance.

It is therefore essential to eliminate as many sources of variation as possible in the many factors that influence measurement results, if tight tolerances are desired. Part of this must be the restriction to particular instruments.

Bridging the Gap

While the paper industry has recognized the need for compatible color values for prepress and printers [14] and starts to add CIELAB D50/2° values according to ISO 13655. But their process control will continue to use their own established standards.

Different strategies are conceivable. There has been some work about comparing and transforming spectral measurements between devices of similar geometry (e. g. [15]), or between hemispherical and bidirectional geometry [16], taking device characteristics into account. This has the advantage of being a general approach which aims to work across a range of surface properties like gloss and roughness, but adds a model error to the overall uncertainty. It is reported that the difference can be typically reduced by a factor of 2–3 under optimum conditions (similar geometry). For different geometries, the remaining error with recent models is still above 2 ΔE [17].

These models typically adjust black level, photometric scale, linearity, wavelength shifts, and bandpass issues (e. g. steepness of spectral edges). For the latter two, the first and second derivatives of the spectra are needed, and the models are best trained with strong colors of different hues [18]. Since we are only concerned with spectrally almost flat paper whites, beside photometric scale we would rather need model parameters for effects which are not distinguished in the approach above, like the degree of specular detection (as examined in [19]), and fluorescent effects like OBA excitation and maybe correction of aperture-dependent second-order fluorescence in the integrating sphere [20].

A simpler approach is a mapping between corresponding measuring values of a pair of devices specific for a single material. Aside from the production tolerance, achievable tolerances are determined mainly by the combined uncertainty of the two devices. Of course one cannot expect to use this mapping even for similar substrates or similar devices and keep the tolerances.

So we decided to establish pairs of values on relevant proofing paper samples together with realistic tolerances, but also to compare and understand the devices itself by an expanded set of samples with very closely defined calibration and measurement procedures.

Paper Samples

We used IR3 standards from Innventia AB, Stockholm, Sweden, as a common basis for calibration. The DX standard is non-fluorescent uncoated paper and comes with certified reflectance values from 360 to 740 nm. The near-UV reflectance is $>$83%, much higher than in most papers. The FB standard is fluorescent with a certified CIE whiteness D65/10° of 152.1 units.

Other samples included some proofing papers of interest and additional photo papers with either high gloss or high FWA activity. All samples were stapled in pads (stacks) of 3 mm thickness (using at least 5 sheets plus a labeled top sheet) and cut to the same size as the DX and FB standards, namely 72 mm × 140 mm. Like the DX and FB standards, the measurement area to be used was on the first sheet below the top sheet, a circle of 42 mm diameter with its center 42 mm away from the short border.

A list of samples and some properties is given in Table 2. Gloss has been measured with a Konica Minolta Multi-gloss MG268 at 20°, 60°, and 85°. The 60° values are given here. ΔB is an estimate of fluorescence components according to ISO 15397, where faint corresponds to $\Delta B<4$, low is 4–8, moderate 8–14, high $>$14. Measurements were taken with a Konica Minolta FD-7 which calculates ΔB from 45a:0° measurements of D65 Brightness minus Brightness at 410 nm UV-cutoff.

Instruments and Procedures

7 X-Rite Spectrolinos (Tab. 3), no-filter (M0), were used as typical handheld instruments from the graphic arts. They were driven by the basICColor catch software v3.1 or directly via serial terminal. The Spectrolino is a single-beam instrument and therefore requires frequent white calibration (recommended is every 50 measurements). It has an aperture of 4.5 mm according to the manual [21]. We measured the opening to be 4.5 mm and the illuminated area to be 3–3.5 mm in diameter using translucent paper.

For the paper industry, we have used the following dual-beam benchtop instruments (see also Tab. 3):

A Datacolor Elrepho 450 [22] and a 650 (di:8°, de:8°) [23], driven by the Datacolor Tools software. Both have the same size

Table 2. List of samples and their properties. ΔB is an estimate of fluorescence components (see text).

No.	Type	Weight g/m^2	Gloss 60°	ΔB
	IR3 paper standards			
DX	non-fluorescent uncoated		4	0.1
FB	fluorescent uncoated		5	25.7
1	semimatte proofing paper	250	17	1.1
2	semimatte proofing paper	200	26	0.2
3	glossy proofing paper	250	46	1.5
4	semimatte proofing paper	250	21	0.5
5	semimatte proofing paper	200	22	0.2
6	glossy proofing paper	250	41	0.6
7	semimatte proofing paper	250	41	10.6
8	matte proofing paper	150	3	10.8
9	satin photo paper	250	19	18.0
10	extra-glossy photo paper	250	90	23.5
11	glossy coated paper	250	48	18.7

Table 3. List of instruments and codes.

Code	Type, S/N	Date
	L&W Elrepho Code 070	Installed
C5	S/N 2227	11/2010
C6	S/N 2243	09/2010
ET	S/N 8802587	04/2012
	Datacolor Elrepho LWE450-X	
E450	S/N 1767, Firmware V9.22	
	Datacolor 650	
650	S/N 8805303, Firmware V9.27	
	X-Rite Spectrolino	Recert.
10299	Rev. D, Firmware 1.72	03/2013
11245	Rev. C, Firmware 1.72	01/2013
14018	Rev. C, Firmware 1.72	02/2013
16735	Rev. C, Firmware 1.72	01/2013
17010	Rev. D, Firmware 1.72	05/2013
19076	Rev. E, Firmware 1.72	10/2013
19077	Rev. E, Firmware 1.72	04/2013

of the barium-coated integrating sphere (152 mm) and the same kind of spectral detector. Elrephos have a d:0° geometry with a matt black ring (ca. 16° half-angle) around the detection port (with a detection cone half-angle $<4°$). The ring acts as gloss trap but can slowly accumulate dust, and is therefore inferior to the real black trap of the 650 for specular excluded measurements.

Additionally, we used 3 Lorentzen & Wettre Elrephos Code 070 [24] installed at the paper production site. These Elrephos are technically very similar to the 450 but driven by the L&W Colour Brightness software (version 2.60.1, ET: 2.60.3).

UV filter conditions D65, 395, 420, 460

Elrephos are UV-calibrated by adjusting the position of a UV-cutoff filter in the illuminating beam (from xenon flashes). In old instruments, filters with other cutoff wavelengths (390–400 nm) have been used. All newer instruments, including those used in our study, use a Schott GG395 cutoff filter.

Typical OBAs for papers can still be considerably excited above 395 nm. The exact wavelength position of the filter edge influences results, so that the paper manufacturer chose to specially equip all its devices by 395 nm filters from the same lot.

Aside from the D65-calibrated (UV-included; UVI) measurements it is also possible to measure with three different UV-excluded (UVO) conditions using the said 395 nm, or a 420 or 460 nm cutoff filter (GG420, GG455), which are then completely moved into the light path. The OBAs are still slightly excited above 420 nm. Therefore the 395 and 420 filters do not suppress OBA activity, and measurements are not exclusively dependent on the paper shade recipe. The 460 nm filter blocks OBA excitation completely but also affects colorimetric results.

In ISO 2469, UV adjustment refers to a 395 nm filter. In contrast, fluorescence elimination (UV-excluded) defines a cut-off filter with less than 5 % transmittance at or below 410 nm and exceeding 50 % at 420 nm. It is explicitly mentioned that a "reliable radiance factor value is obtained at 420 nm". This means that the use of the historical 460 nm filter is non-standard. It is nevertheless common production practice at the paper manufacturer, and Δb* (UVI-UVO 460) is used as the indicator of OBA activity. So one has to be aware that "ideal cutoff is not attainable" [20] and each compromise has its drawbacks.

Calibration Procedure

Measurements were done in climate-controlled laboratories (ISO 187:1990 standard climate with 23°±1° C temperature and (50±2) % relative humidity) at the production site or at our site.

The Elrephos require a first black&white calibration with a black trap and a white standard with known reflectance factors, where we used our DX standard. Then a UV calibration follows which involves adjusting a digital control value for a movable 395 nm cut-off filter until either a brightness value, or in our case, the given CIE whiteness value for the FB standard is achieved.

Since a changed filter position changes the light source, further cycles of black&white calibration and UV filter adjustment are needed until the result is stable (typically three). We used the DX and FB standards each time (not working standards) and handled them carefully as to keep deterioration to a minimum.

The Innventia standards are certified only for the d:0° geometry [25] so that no reference values are available for the de:8° (specular excluded, SCE) or di:8° (specular included, SCI) conditions of the 650. Rich et al. [18] note that SCE is difficult to recommend for calibration due to many geometry-dependent influences. By (mis)using the d:0° data anyway, we found for SCE calibration that readings are well comparable with the Elrephos, and even excellent for b*. SCI calibration on the uncoated matt standards led to readings with increasingly higher L* compared to the Elrephos when sample gloss increased.

At the paper production site, the L&W Elrephos are normally calibrated according to the company's white standard, which differs slightly from the certified IR3 standards by roughly +0.1 b* for non-fluorescent samples. The instrument at the extruder (ET) was used continually, therefore no change in calibration was possible. The other instruments (C5 and C6) could be temporarily calibrated to our DX and FB standards for better comparison with the Datacolor instruments.

Our translation of production target values to graphic arts values must of course be based on the company's standard.

Measurement Procedure

We examined the following variants: multiple measurements without moving the sample; repeating the sample sequence (which means re-positioning); repeating the sequence with full re-calibration. We always measured the DX and FB standards as first samples as a quick check of the white and UV calibration, followed by the numbered samples in sequence. The orientation of the sample pads was fixed.

The Elrepho is typically used with its XLAV aperture, even if large ports increase additional fluorescence from re-excitation [20], but has also SAV and USAV apertures. The 650 has LAV, SAV, and USAV. The diameters in mm of the detected and illuminated areas are: XLAV 30/34, LAV 26/30, SAV 5/9, USAV 2.6/6.6. Each aperture needs its own calibration. It is difficult to place the samples from below the port, especially for the smaller apertures, where we used 5 positions in a quincunx. We used a mirror and adhesive tape to mark the positions. On the 650, the samples are mounted vertically and can be observed easier.

Results

Repeatability

For short-term repeatability, multiple measurements were done without sample replacement [10]. The Spectrolino was set on its white tile. We performed a cold calibration followed by 10 measurements with no delay, then another calibration followed again by 10 measurements. The heating of the tungsten filament apparently increased resistance and therefore lowered current, temperature, and blue light output (ΔL^* drift of -0.1, Δb^* of $+0.05$). After the warm calibration results were typically stable within ± 0.01 ΔL^* and Δb^* without appreciable drift, thus confirming the stated short-term repeatability of 0.03 ΔE as mean value of 10 measurements every 10 s on white [21].

The L&W Elrephos were used to measure each sample three times. The maximum ΔL^*, Δa^*, and Δb^* were calculated. The non-fluorescent samples showed less than 0.03 difference for 395, 420, and D65 conditions (except in one case). But they also showed the highest difference (0.04 Δa^*; 0.08 Δb^*) for the 460 condition. The fluorescent samples had the highest differences under the strong D65 UV excitation (0.06 Δb^*). All in all, the short-term repeatability was often only 0.01–0.02 ΔE, and always less than 0.1 ΔE. Compared to this, the stated repeatability refers only to the white ceramic tile, a condition which we didn't test. L&W state <0.01 ΔE, while the Datacolor manuals for the 450 [650] state 0.02 [0.015] ΔE (max) for 20 reads on the white tile, 2 flashes each. This seems to be realistic.

For long-term repeatability, we measured with the Datacolor devices at our site before and after the L&W measurements at the paper manufacturer. However, our first round of measurements was still with automatic UV calibration and thus less precise than the second series 11 days later. So only the non-fluorescent samples give a good indication of the combined effects of sample degradation and long-term repeatability.

For the 450 with XLAV aperture and UVI we found maximum differences of $|\Delta L^*|=0.02$ [0.03], $|\Delta a^*|=0.02$ [0.04], $|\Delta b^*|=0.05$ [0.13] for the non-fluorescent [fluorescent] samples. Note that the b* change was always negative for the fluorescent samples. This makes OBA degradation unlikely and is consistent with a slightly too low CIE whiteness in the first series and a slightly stronger UV excitation in the second.

For the UVO420 [UVO460] filter conditions, we found maximum differences of $|\Delta L^*|=0.04$ [0.04], $|\Delta a^*|=0.08$ [0.03], $|\Delta b^*|=0.13$ [0.08] over all samples, with no distinction of OBA content. The UVO460 condition seems to be less sensitive for changes.

Inter-Instrument Agreement

The typical Spectrolino inter-instrument agreement is given as 0.3 ΔE average, 0.8 max, based on 12 BCRA tiles [21]. This agrees with our sample-based data in Fig. 1 (discussed later).

We compared the benchtop instruments within a given calibration, either our DX/FB or the paper manufacturer's company standard, Datacolor E450 and 650 to L&W C5 and C6. The L&W Elrephos with selected filters and direct calibration on DX/FB were very close (no CIELAB component difference larger than 0.2 for UVI-D65 and UVO-460; 0.3 for UVO-420 and UVO-395). Only the extra-glossy sample 10 had larger differences.

Similar for the Datacolor E450 and 650 (SCE) despite their difference in hemispherical geometry, but in this case sample 10 was much better. All three L&W Elrephos with company calibration (using working standards) were still within 0.4. Same for the three Elrephos with DX/FB calibration except for sample FB.

Sample FB had the highest $|\Delta b^*|$ for UVO-420 and UVO-395 in all groupings of instruments, providing the extreme UVO-395 values of 0.98 and 1.45, with samples 09, 10, and 11 close behind. This demonstrates that UVO-420 and UVO-395 are less stable measuring conditions for highly fluorescent samples.

For the 450 [650], Datacolor states an inter-instrument agreement as 0.40 [0.15] ΔE (max) and 0.20 [0.08] ΔE (avg). L&W state a reproducibility of <0.25 ΔE (avg) on NCS color samples.

Influence of Aperture

On paper measurements, there is usually much less variation in a* than in the other two dimensions L* and b*. Therefore, covariance ellipsoids from multivariante error analysis are extremely flat, and volumes become meaningless [10]. We have therefore decided to use mainly two-dimensional ellipses which has the added benefit of providing quantitatively illustrative plots. There haven't been any measurements which are far outside of the ellipses with extended coverage (k=2) which would have indicated some unknown error in handling or during measurement.

Between the 7 Spectrolinos in no-filter mode there are clear trends: some instruments measure brighter, some measure bluer than others. Each instrument on its own had similar uncertainties in the order of 0.1–0.3 ΔL^* and 0.1–0.2 Δb^*. Sample 11 has a much larger range in b* (see Fig. 1). It has a visually slightly structured, uneven gloss.

The correlation between L* and b* is often similar for all instruments, but different for samples. Some samples (01, 09, 10) have a more pronounced diagonal ellipse, which could be an indication of uneven blue paper dye. Antidiagonal alignment would mean brighter when bluer e. g. due to an uneven OBA effect, but we didn't observe this.

In order to study the influence of the much smaller Spectrolino detection area, we added another set of Elrepho measurements with smaller apertures. SAV (5 mm) has more twice the detection area than the Spectrolino (assuming 3.5 mm), USAV (2.6 mm) about half the area. Compared to the XLAV data the range of values increased dramatically (Fig. 1, bottom right).

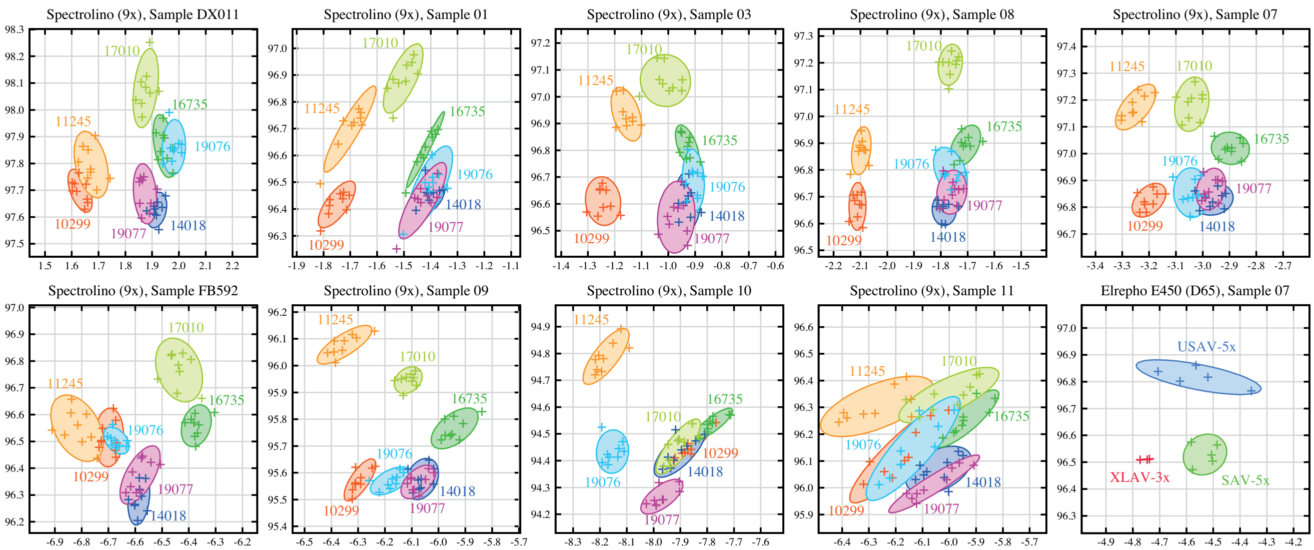

Figure 1. *Spectrolino measurements (D50/2°). 9 positions on sample in a 3×3 diamond shape. There are systematic trends. L*b* plot with 0.1 unit grid. Bottom right: Elrepho 450 (D65/10°) with XLAV (30 mm), SAV (5 mm), and USAV (2.6 mm) detection. SAV+USAV: 5 positions on sample in a quincunx shape.*

Thus, a fair comparison between Spectrolino and Elrepho results must be based on similar detection areas. The Spectrolino needs about 69 measurements to cover the detection area of the XLAV aperture. This could be easily and repeatably managed by using the SpectroScan xy-table. The results can not only be averaged, reaching roughly the precision of the XLAV Elrepho data as expected (data not shown), but also confirmed the different sample inhomogenities which are already visible in Fig. 1.

Adjusting Measurements

From Fig. 1 it is also apparent that averaging many measurements to simulate larger apertures is not going to reduce the differences among the 7 Spectrolinos. Using any single instrument will always introduce a bias. A first attempt on aligning these would be to normalize to a nonfluorescent white reference. While each Spectrolino is already calibrated to its own white tile, all of which in turn have been certified by X-Rite in the yearly recalibration service, the pattern of differences is already apparent on the DX sample. This could be caused by surface reflection. On the glossy tile and the extra-glossy sample 10, gloss is reliably reflected away from the sensor, and the L* range is indeed smallest on sample 10 (with exception of instrument 11245, but this is brighter and bluer at the same time for all highly-fluorescent samples 9–11 and thus might have stronger OBA excitation than the others).

Analoguous to the Elrepho calibration, we used the each instrument's average (center of ellipsis) on DX to adjust the values, and found that the maximum differences decreased slightly for faintly fluorescent samples (|ΔL*| from 0.8 to 0.6, |Δa*| unchanged at 0.2, |Δb*| from 0.5 to 0.3), but not for highly fluorescent ones, where |Δb*| actually increased from 0.6 (see Sample 10 and 11 in the figure) to 0.8.

The former result suggests to examine a connection with sample gloss, the latter a connection with fluorescence intensity, e. g. measured by ΔB. We tried a linear regression of each instrument's deviation from the average over all instruments, against either gloss or fluorescence, or both (Fig. 2). The center of ellipses from Fig. 1, which are the averages of the 3×3 measurement positions, are plotted against gloss or ΔB from Tab. 2. There are some trends but also interactions, so that a single trend does not explain much of the variation. Only by combining two linear trends, the inter-instrument differences can be reduced to less than ±0.1 CIELAB units (with a single outlier), which is an improvement by a factor of 3 in ΔL* and Δb*.

Conclusions

The typical Elrepho measurements (with XLAV aperture) were in excellent agreement. The UV-calibrated and the 460 nm UV-cutoff conditions were more stable than the 420 and 395 nm ones, which had larger b* for highly fluorescent samples. Using company working standards for calibration increased the maximum per-component CIELAB difference from 0.2 to 0.4.

The influence of aperture was considerable, which demonstrated that the samples were less uniform than expected. When the Spectrolino measurements were automated and averaged to cover the same measurement area, repeatability (with the same instrument) was improved. Reproducibility (with other Spectrolinos) was improved to the same precision as the Elrephos by detrending the data against gloss and fluorescence response.

With these findings, measurements from both types of instruments can be aligned based on sample type to monitor tolerances well less than 1 ΔE, which enables the desired high-precision paper color communication across different technologies.

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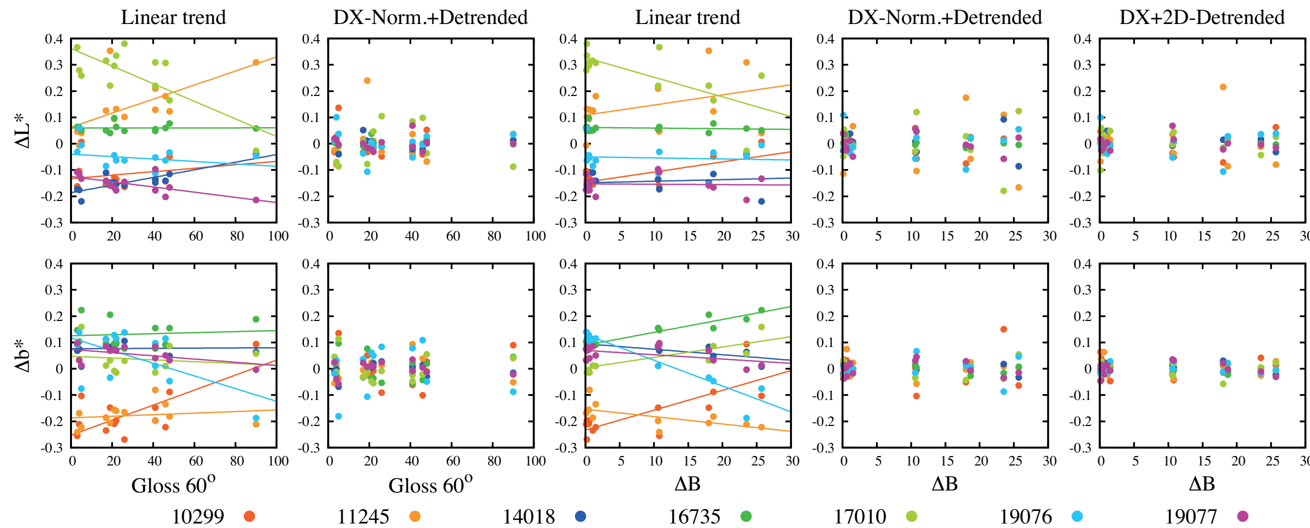

Figure 2. *Detrending Spectrolino data (averages of the 3×3 measurements). Left: trends of single instruments against the average versus gloss, same data and variation as in Fig. 1. Then: detrending after normalization on the matte and non-fluorescent DX sample. Middle: trends, this time against fluorescence ΔB. Then: detrending again. Right: two linear trends have been simultaneously fitted to gloss and ΔB. Most of the residual variation in ΔL* and Δb* is removed.*

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