Inter-Model Agreement Under M1 Conditions and the Implications for Graphic Reproduction

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Abstract

In the latest revision of the ISO 13655 standard (Graphic technology — Spectral measurement and colorimetric computation for graphic arts images) four measurement modes, the "M" series, were precisely defined in order to help standardize the settings for measurements of color. Sun Chemical's customers are particularly concerned with the measurements of white substrates that exhibit a presence of optical brightening agents (OBAs). It is known that these substrates can have a significant influence on the measurements of lighter colored inks, especially transparent process inks, and produce noticeably different results based on the instrument used to capture the spectral radiance factors of the specimen. The main purpose for revision of the ISO 13655 standard was to eliminate the inconsistencies in measured data from press prints and contract proofs arising from the variation in the UV content between instruments and to allow for effective inter-instrument data comparison.

A set of white and near-white specimens was selected for an experiment in which the agreement level between three different commercial instruments in M1 mode was assessed. The data indicate that there are still discrepancies in measurements between the instruments when various manufacturers' M1 measurement conditions are used. These variables can directly affect any other indices or values derived from the measured data based on M1 conditions. In an attempt to improve the agreement of the three instruments the spectral data were normalized to a non-fluorescent material. The results indicate that differences in geometry play a large role in the inter-instrument agreement in the characterization of optically brightened paper substrates.

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Introduction

In the latest revision of the ISO 13655 standard (Graphic technology — Spectral measurement and colorimetric computation for graphic arts images)[1] four measurement modes, the "M" series, were precisely defined in order to help standardize the settings for measurements of color. Reproduction engineers are particularly concerned with the measurements of white substrates that contain optical brightening agents (OBAs). It is known that these substrates can have a significant influence on the optical measurements of lighter colored inks, especially transparent process inks [2], and will produce noticeably differing results based on the instrument used to capture the spectral radiance factors of the specimen. The main intention for revision of the ISO 13655 standard was to eliminate the inconsistencies in measured data coming from the variation in UV content between instrument models typically used for measuring printing substrates with higher levels of OBAs and to allow for effective inter-instrument data comparison. The M1 mode was specifically defined to simulate the spectral power distribution for CIE illuminant D50 and requires the colorimetry of the instrument illumination to closely match spectral power distribution of the illuminant D50. The other intention for using the newly defined M1 mode is to be able to quantitatively classify the grade of white printing papers in terms of ISO Brightness or the newly proposed Brightness Index[3].

It has been reported that spectrocolorimeters exhibit much better precision (repeatability) than reproducibility (inter-instrument agreement)[4] [5]. If the M1 standard works as intended, then it should allow the characterization of fluorescent white substrates to have an inter-instrument agreement equal to that observed in a non-fluorescent material. This would be in contrast to results reported by the CIE [6] in which the color measurements of fluorescent materials was observed to have a reproducibility that was an order of magnitude worse than the reproducibility of non-fluorescent materials. That was reported to be the case even when the locations were regional, national or corporate standardizing laboratories. This study was to examine the intent of the ISO TC 130 Working Group 3 for improving the agreement between instrumental assessments of printing on modern papers using instruments from different manufacturers.

Experimental procedure

A set of 50 paper substrates was collected for testing. The CIE Whiteness Index (per ASTM E313 [7]) ranged from a low of 57 to a high of 133. While both fabrics and plastics have been reported in the literature [8] with Whiteness Indices above 150, the range used in this study was thought to be wide enough to provide an adequate test of the M1 concept.

Three modern portable spectrocolorimeters, all with 45°:0° (influx : efflux) ISO 5-1 compliant geometry [9] were used for the characterization tests. The instruments are typical of commercially available instruments for the control of the color of printing at the press-side. The instruments were standardized following the manufacturer's instructions prior to each set of readings. The instruments were configured to be in compliance with either M0, M1 or M2 measurement modes. Each paper was placed on an ISO 13655 compliant white backing material, the Munsell N925 sheet, and the reflectance factors or radiance factors were captured. The papers were read on three different locations to provide a reasonable estimate of the average reflectance of the substrate. Reports in the literature have shown that due to the high precision of spectrocolorimeters, three readings are generally enough to give a suitable average reading of the spectrum and hence the color of a material object [10]. The spectral total radiance factor data were collected into an Excel workbook and ASTM E308 Table 5-9 [11] was used to compute the tristimulus values for CIE D50 and the CIE 1931 Standard Observer. This then eliminates any instrument specific post-measurement data processing that may be applied during the tristimulus integration. Figure 1 shows the spectral total radiance factor curves for the 50 papers. As can be seen, the curves range from fairly flat spectral curves to very strong fluorescent emissions from the optical brightening agents. The tristimulus values were then transformed into CIELAB coordinates and color differences and pairwise contrasts between instruments computed. The contrasts were performed pairwise for the three instruments, 1 versus 2, 1 versus 3, and 2 versus 3. This is similar to the contrasts reported by Wyble [5]. The repeatability of the three replicate readings was also captured.

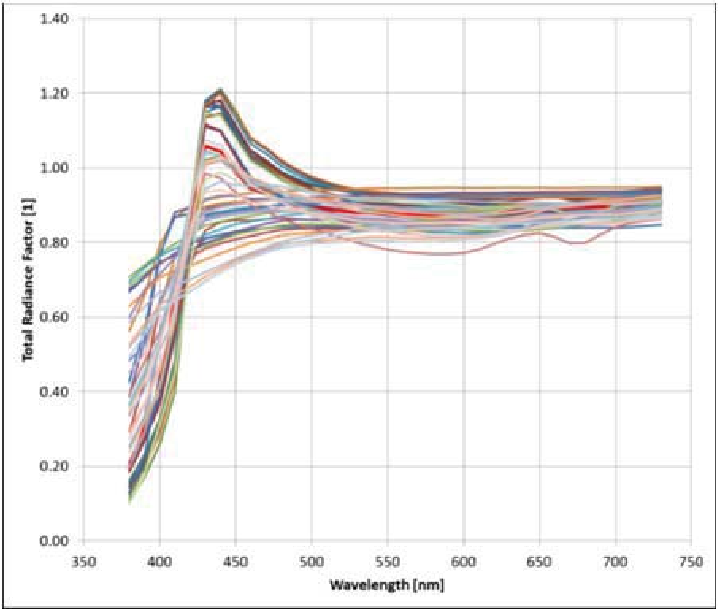

***Figure 1** – Spectral Total Radiance Factor readings of 50 white papers*

While the astute reader will be familiar with the range of instruments available for the purpose of characterizing print using the M1 condition, the authors do not feel that it would benefit either the manufacturers or the user community to identify the make and model of each instrument used in this study.

Results and discussion

Table 1 below gives the results of the pairwise comparison of the three instruments. The short term repeatability for the three readings on each piece of substrate was 0.06 CIELAB units for Instrument 1, 0.09 CIELAB units for Instrument 2 and 0.10 CIELAB units for Instrument 3. Clearly the short-term precision of the instruments is much better than instrument to instrument reproducibility. The numbers in the table below are a bit better than those reported by Wyble and Rich for the white BCRA tile. For the three instruments conforming to (45°:0°) they reported average contrasts of 0.13, 2.1 and 1.9 CIELAB units. Clearly in their study, two instruments were from the same model and one was a different model. Still the numbers in the table below seem to be larger than expected given that the white papers are similar to the reference tiles and have only a small spectral signature. Thus one would assume that instrument properties like wavelength scale errors and bandwidth differences would not play a large role here. In fact, the largest difference in the Instrument 1 versus Instrument 2 comparison, is for paper 33 which is not one of the brightest papers but is a matte finish, presentation paper.

				1 vs 2		
		ΔL^*	Δa^*	Δb^*	ΔE^*	ΔE_{00}
Ave		-0.80	0.07	-0.30	0.96	0.65
Med		-0.76	0.07	-0.32	0.92	0.59
95%		-0.56	0.33	0.41	1.39	0.94
				1 vs 3		
		ΔL^*	Δa^*	Δb^*	ΔE^*	ΔE_{00}
Ave		-0.86	-0.01	-0.08	0.96	0.64
Med		-0.89	0.01	0.04	0.96	0.63
95%		-0.45	0.20	0.40	1.35	0.90
				2 vs 3		
		ΔL^*	Δa^*	Δb^*	ΔE^*	ΔE_{00}
Ave		0.05	0.07	-0.21	0.75	0.66
Med		0.09	0.05	-0.37	0.61	0.53
95%		0.39	0.48	0.90	1.58	1.26

Table 1 *– Pairwise contrasts of the white paper substrate readings under M1measurement mode*

If it can be assumed that the primary cause of the differences between the instruments, for these white papers, is merely the white tile to which the manufacturer is traceable then it should be possible to adjust the scale of reflectance by taking a white specimen and forcing the other instrument to agree on that white paper. After applying that scale factor to all of the other readings, the differences between the instruments should be greatly reduced. The methodology for accomplishing this comes directly out of CIE Publication 130 [12]. A pale gray chip was taken from a ChromaChecker™ [13] test target. The white patch on this target contains OBA, as can be seen in Figure 2 below, so the pale gray was chosen instead. This target was read on each instrument and the pale gray patch was chosen to adjust the scale of the other two instruments. Instruments 1 and 3 were scaled using the data from Instrument 2. This instrument was chosen somewhat arbitrarily as there was no reason to believe that one instrument was any closer to the truth than any other instrument.

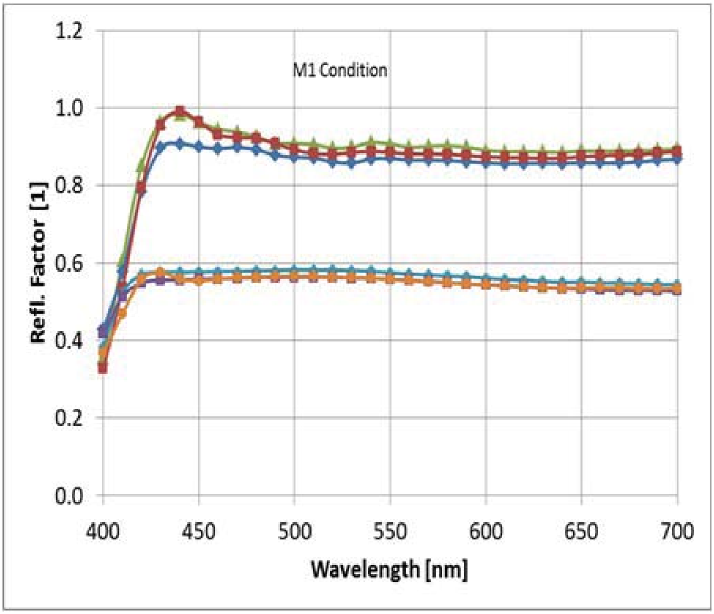

***Figure 2 –** Spectral total radiance factor readings for a white and a pale gray patch on the ChromaChecker™ target.*

On the 42 colored patches in the ChromaChecker™ target the average instrument contrasts for (1v2, 1v3, 2v3) were 0.86, 0.77, 0.64 CIEDE2000 units. The term "contrast" is used here in the statistical sense – indicating the testing of several effects in a pairwise fashion. These average contrasts would imply that the three instruments are rather uniformly separated from each other. The pale gray contrasts were 0.71, 0.69, 0.17 and the white patch contrasts were 1.50, 0.74, 1.82 CIEDE2000 units, respectively. So the fluorescent white was generally more difficult to read than the pale gray, even though the instruments were all operating in M1 mode. Noteworthy, as well, is the indication that instruments 1 & 3 agree better on the white while instruments 2 & 3 agree better on the gray. After applying the rescaling factor, based on the pale gray patch, the average contrasts across all patches were reduced as follows 0.38, 0.49,0.62 CIEDE2000 units. Clearly there were differences in the instrument reflectometer standardizations. On the pale gray patch all color differences were naturally 0.0 and then on the white patch the contrasts were 0.98, 0.67, 1.64. So the scaling improved the reproducibility of the three instruments.

The scaling factor derived by the pale gray analysis was then applied to data collected from the 50 white papers. Table 2 below shows the same information as Table 1 but after the scales had been adjusted.

In Table 2 it can be seen that the average color differences have been reduced in the contrasts between instruments 1 v 2 and between 1 v 3 but not in the case of instruments 2 v 3. There must be something else happening here.

				1 vs 2		
		ΔL^*	Δa^*	Δb^*	ΔE^*	ΔE_{00}
Ave		0.36	0.08	-0.43	0.69	0.53
Med		0.40	0.07	-0.41	0.60	0.43
95%		0.60	0.36	0.29	1.23	0.93
				1 vs 3		
		ΔL^*	Δa^*	Δb^*	ΔE^*	ΔE_{00}
Ave		0.27	-0.08	-0.08	0.54	0.45
Med		0.25	-0.06	0.07	0.51	0.43
95%		0.68	0.12	0.40	0.85	0.68
				2 vs 3		
		ΔL^*	Δa^*	Δb^*	ΔE^*	ΔE_{00}
Ave		0.08	0.15	-0.34	0.81	0.72
Med		0.12	0.11	-0.47	0.69	0.62
95%		0.42	0.57	0.75	1.72	1.39

***Table 2** – Pairwise contrasts of the white paper substrates readings under M1 measurement mode (adjusted)*

Instrument 3 has the smallest illumination aperture and Instrument 1 has the largest illumination aperture. If there was some amount of lateral diffusion of the fluoresced radiance in the translucent papers and coatings then one would expect to see reasonable agreement on prints with some absorbing pigments, such as the gray papers and larger, uncorrected errors in the unprinted fluorescent stocks. This appears to be exactly what is observed.

Instruments 1 and 2 were also utilized for taking readings under the M0 and M2 measurement modes. Tables 3 and 4 below show those results for the 50 paper specimens characterized under M0 and M2 and with the data adjusted by the same non-fluorescent pale gray patch.

For each measurement mode, adjusting the white reference significantly improved the agreement between the two instruments. This is one of the guiding principles behind the X-Rite initiative termed, "XRGA". It is also notable that the improvement in the three measurement modes is about the same for the contrasts between Instrument 1 and Instrument 2. These two instruments have different geometry, different spectral ranges and bandpass yet the white reference plaque accounts for about 50% of the difference between the two instruments. Since the specimens, white papers, have little to no spectral modulation in their spectral radiance factor curves one would expect that the reflectance scale correction would resolve most of the differences between the instruments. But the correction for the white tile removes only about half of the differences so the remaining half must be predominantly a result of the geometry differences between the instruments.

			1 vs 2		
	ΔL^*	Δa^*	Δb^*	ΔE^*	ΔE_{00}
Ave	-1.32	0.11	-0.20	1.39	0.88
Med	-1.29	0.09	-0.23	1.33	0.86
95%	-1.01	0.32	0.39	1.90	1.15
			Adjusted		
	ΔL^*	Δa^*	Δb^*	ΔE^*	ΔE_{00}
Ave	-0.15	0.12	-0.32	0.52	0.43
Med	-0.12	0.09	-0.32	0.51	0.42
95%	0.14	0.34	0.27	0.93	0.72

Table 3 - *Pairwise contrasts of the white paper substrates readings under M0 measurement mode*

			1 vs 2		
	ΔL^*	Δa^*	Δb^*	ΔE^*	ΔE_{00}
Ave	-1.34	-0.04	0.36	1.46	0.96
Med	-1.31	-0.02	0.29	1.45	0.92
95%	-1.06	0.08	1.05	1.96	1.28
			Adjusted		
	ΔL^*	Δa^*	Δb^*	ΔE^*	ΔE_{00}
Ave	-0.18	-0.05	0.28	0.52	0.45
Med	-0.14	-0.03	0.18	0.44	0.41
95%	0.09	0.07	0.95	0.98	0.92

Table 4 - *Pairwise contrasts of the white paper substrates readings under M2 measurement mode*

The white papers were subsampled into two groups. In the first group 4 papers with similar trade names and manufacturers but different basis weights were selected. The papers were all described as smooth coated papers. In the second group, the 4 papers had similar CIE whiteness values but were a mixture of coated and uncoated and smooth and matte surfaces. The two groups were submitted to a main effects MANOVA. The treatments were Paper number and Instrument number. Not surprisingly, as can be seen in Figure 3 below, the paper type was the biggest contributor to the variance and were enormously statistically different. As reported by Wyble [5] the high precision of modern spectrocolorimeters makes even minor differences in the product being tested easily differentiable.

Likewise, the MANOVA results for the second group of dissimilar papers is shown in Figure 4. Here the papers are an even more significant contribution to the differences between readings. Still the instruments are a statistically significant contributor to the overall variance of the experiment.

Effect	Multivariate Tests of Significance (M1_Comparison.sta) Sigma-restricted parameterization Effective hypothesis decomposition Test	Value	F	Effect df	Error df	p
Intercept	Wilks	0.000001	17784023	3	28	0.00
Inst	Wilks	0.001588	225	6	56	0.00
Paper	Wilks	0.000038	488	9	68	0.00

Figure 3 *– MANOVA results for the similar papers of Group 1.*

Effect	Multivariate Tests of Significance (M1_Comparison.sta) Sigma-restricted parameterization Effective hypothesis decomposition Test	Value	F	Effect df	Error df	p
Intercept	Wilks	0.000001	11658293	3	28	0.00
Inst	Wilks	0.011788	77	6	56	0.00
"Paper2"	Wilks	0.000008	949	9	68	0.00

Figure 4 *– MANOVA results for the dissimilar papers of Group 2.*

For completeness, the spectral total radiance factor curves of the two paper groups under each of the ISO 13655 measurement conditions (M1, M0, M2) are shown in Figure 5. The plots show the strong OBA contribution in the papers in Group 1 and the much lesser contribution in Group 2. Paper 43 appears to be almost free from fluorescence.

For reference the proposed Brightness index values (Δb* between M1 and M2) were determined to be (10.0, 10.6, 11.4, 11.1) for the 4 papers in Group 1 and (6.2, 9.0, 6.6, 2.4) for the 4 papers in Group 2. The low Δb* Brightness index for Paper 43 confirms the results observed in the spectral plots.

Again, in the case of the M2 readings, the spectral radiance factors curves show improvements and further reduce the spectral modulation of the measurements but the correction by the gray reference does not further reduce the agreement between the instruments, as observed in Table 4. Clearly, there are uncontrolled variables modulating the differences between the readings and it is here postulated that the unknown variable is the differences in the geometry of the instrument designs. CIE Publication 176:2006 [14] describes the requirements for improving the inter-instrument agreement of spectral reflectance measurements by applying tighter controls on the geometry of the measurement system. But no manufacturers are known to have adopted these CIE recommendations. Similarly, a CIE Technical Committee in Division 2, "Physical Measurement of Light and Radiation" that had been established to develop a new standard on the measurement of visible spectral reflectance factor was disbanded due to lack of participation from either the academic or the commercial instrument development communities.

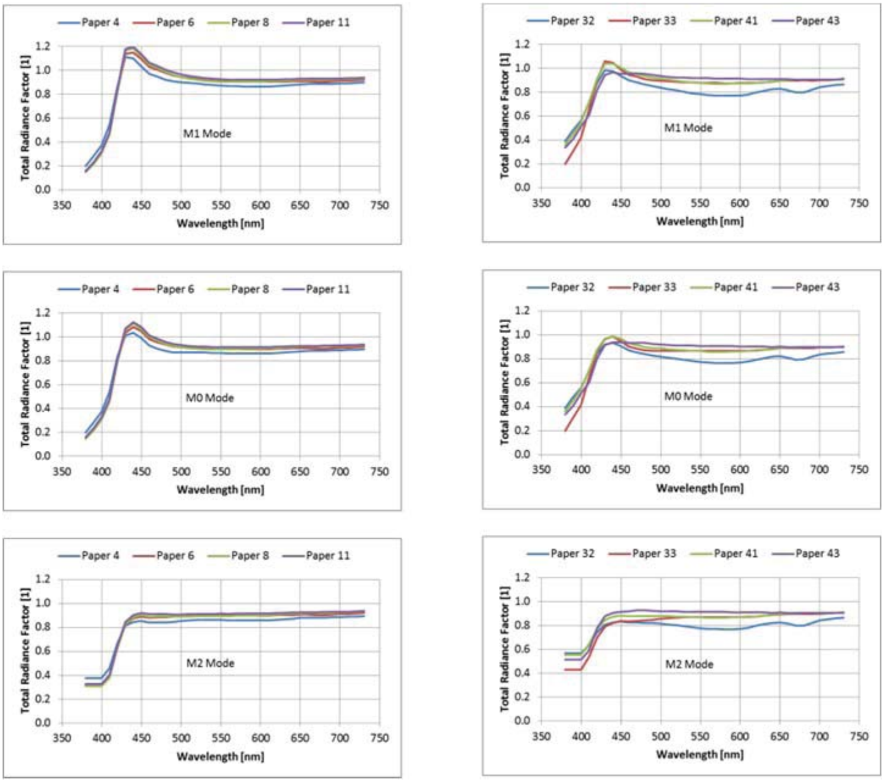

***Figure 5** – Spectral total radiance factor plots of the two paper groups under the three ISO 13655 measurement conditions. Group 1 (similar papers) is on the left and Group 2 (dissimilar papers) is on the right.*

Conclusions

A comparison of three different portable spectrocolorimeters all identified as compliant with ISO 13655 M1 measurement requirements was performed. The instruments were used to assess the total radiance factor for 45°:0° (influx : efflux) geometry, as specified in ISO 5-1. A total of 50 white or near-white papers were utilized and each was characterized three times and the individual readings averaged. The average total spectral radiance factor curves were converted into tristimulus values for CIE D50 and the CIE 1931 Standard Observer. The tristimulus values were then transformed into CIELAB coordinates (L*,a*,b*) and the color difference contrasts between the three instrument (1 vs 2, 1 vs 3, 2 vs 3) were compared. Two of the instruments were then compared under M0 and M2 measurement conditions. The results can be summarized as:

- All instruments demonstrated excellent repeatability across a wide range of paper substrates.
- The M1 process on each instrument resulted in a high level of excitation of the optical brightening agent in the papers.
- The inter-model agreement was improved slightly by adjusting the white scaling factor.
- The inter-model agreement was not significantly better for highly fluorescent materials.
- The inter-model agreement was improved more significantly for papers printed with a neutral ink.
- Differences in geometry of the instruments, especially the size of the illumination and viewing areas had a larger effect on the inter-instrument agreement than the scale of reflectance factor.
- The M1 measurement condition may not resolve all issues related to the agreement between visual and instrumental assessment of print and proofs.

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