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An Evaluation of the Effect of Instrument Geometry on Color Management for Printed Textiles

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Abstract

The present study analyzes spectrophotometers with two different optical geometries, namely unidirectional 45° instruments and spherical 8°instruments, for building ICC profiles of inkjet-printed textiles. Unidirectional 45° instruments are utilized extensively in the graphic arts, while spherical 8° instruments are more commonly used in the textile industry. One limitation to using spherical 8° instruments for ICC profiling is that profiles built of printing conditions typically require readings of hundreds of patches, and there is only one known instrument configuration that can automate this process, while choices abound for automated instrumentation with unidirectional 45° for ICC profiling.

Using a ColorScout A+, a robotic "x,y" table that is instrument agnostic and able to accommodate both handheld unidirectional 45° instruments and spherical 8°instruments in automating multiple readings, profiles are built and analyzed for two different inkjet-printed textile substrates.

Introduction:

The following paragraphs summarize the differences between unidirectional 45° instruments and spherical 8°instruments, for a more detailed discussion readers are encouraged to see Measuring Colour, edited by R. W. G. Hunt, and M. R. Pointer, Wiley, 2011.

Spectrophotometers used in the graphic arts typically utilize a unidirectional light source and 45°optical geometry, in which the sample is illuminated by directional light at 0°, that is, at the normal line perpendicular sample, and the reflected light

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is sensed at 45°. This is known as the 0°/45° optical geometry. Alternatively, the sample can be illuminated at 45° and sensed the 0° normal line, these are referred to as the 45°/0° optical geometry. For practical applications, these optical geometries are considered identical.

Another type of optical geometry is also utilized at times in the graphic arts, known as integrating sphere instruments. These instruments illuminate samples using diffuse light, therefore the sample is lit from multiple angles. With these spherical instruments, the reflected light is sensed at 8° with the illumination at the normal line, known as d/8°, or the sensing is at the normal line with the illumination at 8°, known as 8°/d. Again, for practical applications these optical geometries are considered identical.

Unidirectional 45° instruments dominate in the printing space, largely because they are the only type of devices that can measure status It is relevant to recognize the difference between specular reflection, often manifest as gloss, and diffuse reflection when discussing instrument optical geometry. Objects with smooth surfaces primarily exhibit specular reflection where incident light is reflected at the same angle to the surface normal of the incident. If viewed at normal, the specular reflection is generally not sensed. In an extreme example, to 45° instruments a mirror is recorded as near-black, regardless of the color tint of the mirror. As a glossy surface illuminated at 45° does not reflect the spectral component at the normal line, it is helpful to think that unidirectional 45° instruments exclude the gloss in their measurement of color.

Spherical instruments, on the other hand, allow for the spectral reflectance to be included in the measurement in a condition known as specular included. In addition, these instruments can allow for the spectral reflectance to be trapped or otherwise escape, and therefore not be included in the reading, in a condition known as specular excluded. While all 45° instrument exclude the spectral component, these are not the same as spherical instruments with the specular reflectance excluded, as the spheres are using diffuse illumination rather than unidirectional and measuring an 8° rather than 45°.

After measurement, resulting profiles were measured quantitatively using a numeric color volume, plus they were ‘round-tripped’ and spot readings were analyzed. Qualitative analyses included an examination of the graphic representations of the resultant gamut shapes and volumes to validate qualitative results.

Materials / Equipment:

ColorScout A+ x,y Table
X-Rite 939 Unidirectional 45° Spectrophotometer
Konica Minolta CM2600D Spherical 8° Spectrophotometer
X-Rite i1 Publish Software
Microsoft Excel Software
ColorThink Pro Software for Profile Evaluation
Vutek GS 3250 Inkjet Printer, UV Curable Ink with Caldera Raster Image Processor
Ultra-Cotton Textile Substrate (highly textured)
Samba Substrate (low texture, higher gloss)

Methods:

Using the Vutek Printer, all color management was turned off at the Raster Image Processor (RIP) level. IT8 7/3 targets consisting of 1,617 individual color patches were output on each of the Ultra-Cotton (highly textured) and SAMBA (low texture with gloss) textile substrates.These were then read with the 45° Spectrophotometer and the Spherical 8° Spectrophotometer using the ColorScout A+ x,y table. Resulting data were formatted in CGATS.17 - 2009 format for building ICC profiles at default settings using X-Rite i1 Profiler (otherwise known as i1 Publish) software. Resultant profiles were analyzed using ColorThink Pro software.

Results:

Quantitative Analysis together with qualitative evaluations were performed of ICC Profiles using ColorThink Pro software, along with analyses of spot readings of selected patches using colorimetric values to investigate possible variance introduced by instrument orientation to the substrate. Specifically, gamut volumes were analyzed both quantitatively and qualitatively, profiles were subject to a round-trip test to evaluate profile accuracy, followed by a spot-reading directionality analysis.

Gamut Volumes:

Gamut volumes are reported, and validated by a visual analysis of those same gamuts. Table 1 illustrates the gamut volumes of the various substrate and instrument combinations, as reported by the ColorThink Pro software.

	Ultra-Cotton	SAMBA
45°	253,231	250,155
Sphere Specular Excluded	236,232	195,429
Sphere Specular Included	224,914	210,523

Table 1: *Gamut Volumes*

The data presented in Table 1 are validated by visual analysis of the gamut volumes, as shown in Figures 1 and 2.

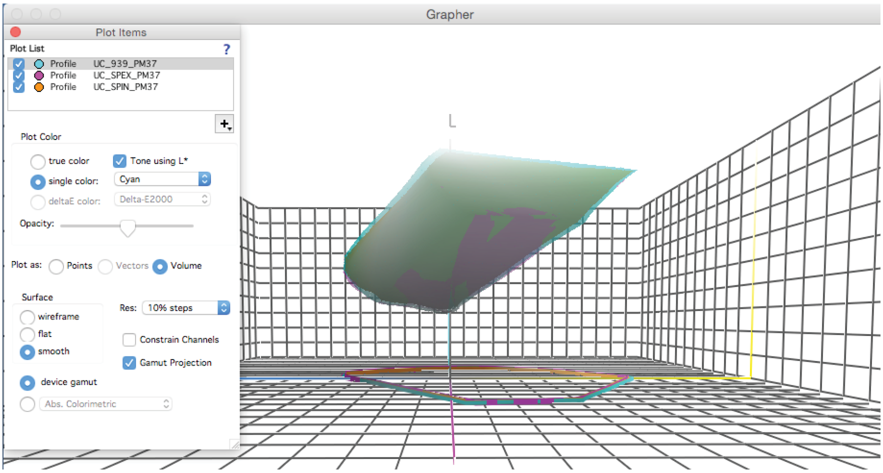

Figure 1: *Visual Analysis of Gamut Volumed: Ultra-Cotton Substrate*

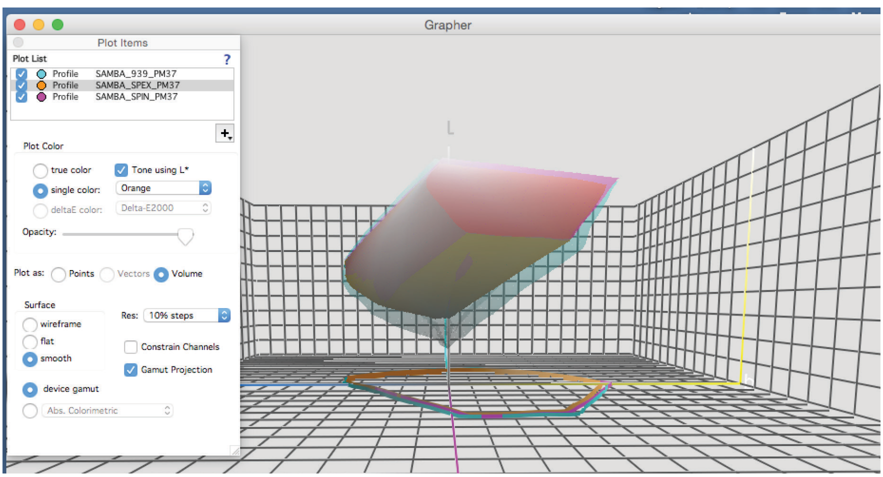

Figure 2: *Visual Analysis of Gamut Volumed: SAMBA Substrate*

Round-trip Profile Analysis

In addition to examining the gamut volumes, ColorThink Pro software was utilized to round trip the profiles. Using a method recommended by CGATS TR016 Graphic Technology Printing Tolerance and Conformity Assessment, and outlined in Sharma (2004) profiles were transformed in the forward direction (device to Profile Connection Space (PCS)) in order to map the gamut boundary of the profile. The goal of this step is for the resultant LAB values to describe the gamut of the printer. These values are mapped back to the printer using the inverse transform (PCS to device). Finally, the printing device values are subject to a second forward transform (device to PCS). Delta-E values are calculated between the beginning and ending LAB values. When Round-Tripped Delta-E vales are sorted from the largest to the smallest, the 81st value represents 95th percentile, and indication of the quality of the profiles in regard to the reversibility of the output profile lookup tables. Resulting data from the round-trip test is presented in Table 2.

	Ultra-Cotton	SAMBA
45°	2.76	5.31
Sphere Specular Excluded	2.69	2.64
Sphere Specular Included	2.71	2.61

Table 2: *95th Percentile ΔE_{00} from Profile Round-Trip Test*

Spot Readings for Instrument Directionality

In a final quantitative test, spot readings were taken of selected patches in which the orientation of the measurement device was rotated at 45° increments, resulting in eight readings of the same spot in each patch with the only difference being the angle of the instrument. For this test, readings of the substrate, 100% black, a rich black consisting of 85% Cyan, 85% Magenta, 85% Yellow and 0% Black, and a 400% coverage consisting of 100% Cyan, 100% Magenta, 100% Yellow and 100% Black were measured. Data from this test is presented in Table 3-6.

Ultra-Cotton				SAMBA			
$\bar{X}$	45°	Sphere Included	Sphere Excluded	$\bar{X}$	45°	Sphere Included	Sphere Excluded
L*	93.51	92.94	93.05	L*	93.18	92.63	92.76
a*	1.98	1.46	1.35	a*	1.94	1.49	1.38
b*	-5.59	-3.12	-3.09	b*	-5.71	-3.66	-3.62
C*	5.93	3.45	3.37	C*	6.03	3.95	3.88
h°	289.44	294.99	293.66	h°	288.76	292.18	290.93
Range				Range			
DL*	0.39	0.2	0.19	DL*	0.64	0.3	0.28
Da*	0.07	0.08	0.11	Da*	0.07	0.12	0.15
Db*	0.31	0.1	0.12	Db*	0.37	0.22	0.2
DC*	0.3	0.1	0.14	DC*	0.36	0.19	0.19
Dh°	0.05	0.04	0.05	Dh°	0.07	0.12	0.12

Table 3: *Directional Spot Readings of Substrates at 45° increments, eight readings per spot*

Ultra-Cotton				SAMBA			
$\bar{X}$	45°	Sphere Included	Sphere Excluded	$\bar{X}$	45°	Sphere Included	Sphere Excluded
L*	33.03	33.04	33.62	L*	34.36	35.57	36.14
a*	0.7	0.62	0.61	a*	0.49	0.43	0.43
b*	0.63	0.9	0.8	b*	-0.33	0.05	0
C*	0.94	1.09	1.01	C*	0.59	0.43	0.43
h°	42.25	55.14	52.6	h°	325.74	7.17	0.38
Range				Range			
DL*	0.37	0.17	0.18	DL*	0.67	0.16	0.04
Da*	0.08	0.04	0.07	Da*	0.06	0.05	0.06
Db*	0.17	0.04	0.06	Db*	0.22	0.07	0.07
DC*	0.11	0.04	0.08	DC*	0.1	0.05	0.06
Dh°	0.09	0.02	0.03	Dh°	0.13	0.03	0.03

Table 4: *Directional Spot Readings of 100% Black (0C, 0M, 0Y, 100K) at 45° increments, eight readings per spot*

Ultra-Cotton				SAMBA			
$\bar{X}$	45°	Sphere Included	Sphere Excluded	$\bar{X}$	45°	Sphere Included	Sphere Excluded
L*	33.03	33.04	33.62	L*	34.36	35.57	36.14
a*	0.7	0.62	0.61	a*	0.49	0.43	0.43
b*	0.63	0.9	0.8	b*	-0.33	0.05	0
C*	0.94	1.09	1.01	C*	0.59	0.43	0.43
h°	42.25	55.14	52.6	h°	325.74	7.17	0.38
Range				Range			
DL*	0.37	0.17	0.18	DL*	0.67	0.16	0.04
Da*	0.08	0.04	0.07	Da*	0.06	0.05	0.06
Db*	0.17	0.04	0.06	Db*	0.22	0.07	0.07
DC*	0.11	0.04	0.08	DC*	0.1	0.05	0.06
Dh°	0.09	0.02	0.03	Dh°	0.13	0.03	0.03

Table 5: *Directional Spot Readings of Rich Black (100C, 85M, 85Y, 0K) at 45° increments, eight readings per spot*

Ultra-Cotton				SAMBA			
$\bar{X}$	45°	Sphere Included	Sphere Excluded	$\bar{X}$	45°	Sphere Included	Sphere Excluded
L*	27.82	29.75	30.65	L*	14.93	28.35	30.89
a*	1.17	1.33	1.29	a*	0.89	1.38	1.38
b*	0	0.09	0.01	b*	-0.06	0.23	0.23
C*	1.17	1.34	1.29	C*	0.89	1.4	1.4
h°	359.87	3.68	0.32	h°	356.13	9.52	9.65
Range				Range			
DL*	1.92	0.38	0.49	DL*	1.43	0.58	0.38
Da*	0.3	0.1	0.08	Da*	0.35	0.17	0.15
Db*	0.51	0.07	0.08	Db*	0.23	0.13	0.09
DC*	0.3	0.09	0.08	DC*	0.35	0.16	0.15
Dh°	0.26	0.04	0.05	Dh°	0.13	0.09	0.04

Table 6: *Directional Spot Readings of 400% Coverage (100C, 100M, 100Y, 100K) at 45° increments, eight readings per spot*

Analysis:

In examining the gamut volumes, the SAMBA low-texture, high-gloss substrate resulted in a larger 45° profile than the spherical profiles of the same substrate, up to 20% less gamut volume. This is validated by a visual analysis of the gamut volumes, where the difference is most dramatic in the darker regions. This particular combination also resulted in the worst performance in the round-trip profile test, where the 95th percentile ΔE_{00} for the unidirectional 45° instrument profile was 5.31, versus 2.61-2.76 ΔE_{00} for the other instrument and substrate combinations. This indicates that gloss may be a greater influence in profile accuracy than texture when building profiles of textile substrates.

Turning to the spot readings to analyze instrument orientation versus the substrate, it is interesting to note that for the substrate alone, the greatest variance is in the unidirectional 45° instruments, most evident in lightness (L*). Interestingly, the SAMBA low-texture, high-gloss substrate resulted in nearly twice the range in lightness variance of the Ultra-Cotton substrate. When 100% black is measured, similar results were noted. When higher amounts of ink coverage are measured in the rich black (100%C, 85%M, 85%Y, 0%K) and 400% (100%C, 100%M, 100%Y, 100%K), the range in lightness for the unidirectional 45° instruments far exceeded that of the spherical devices, and greater differences were noted in hue and chroma, as well.

Perhaps the most telling result from the spot readings at the high amounts of ink coverage is the difference in lightness between the unidirectional 45° instruments and the spherical instruments in terms of the average of the eight readings at the various directions with the SAMBA substrate: the 400% coverage sample was over 45% lower in L* with the 45° instrument. This is likely a contributing factor in the differences noted in the profiles.

Conclusions and Implications:

As textile printing continues to grow, printers need to better understand color management concerns for the unique substrates represented by this process. It is hoped that the present study helps to begin a dialogue about the possibility of using spherical instruments for color management, in an area that has traditionally been dominated by unidirectional 45° devices.

While measurements that result in ICC profiles are often only utilized in a relative, rather than an absolute, manner, the choice of instrument geometry may not be viewed as critical, with practitioners falling back on the instruments that served them well with paper substrates. However, if nothing else the present research suggests that the orientation of the instrument relative to the substrate needs to be consistent, and therefore represents a variable that users need to acknowledge.

Further, controlling for variance introduced by gloss and texture are additional factors that should be recognized by those wishing to optimize existing tools in new applications.

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