Applications Note

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Opacity Compensation for Paper Using the SpectraProbe XE

The opacity of paper can affect its color. For single-sheet measurements in particular, a change in opacity results in a change in color. When taking color measurements in a laboratory using a benchtop instrument, a "stack" is created by folding the paper a number of times until it appears opaque. However, an on-line instrument viewing paper as it is manufactured can only measure a single thickness of paper as it passes under the sensor, so the color values may be different than those obtained from a benchtop instrument because the opacity is different.

HunterLab has developed hardware and software options that together compensate for these differences in opacity. The hardware moves an everwhite backing tile underneath the paper and then away from the paper. The software calculates color corrected for opacity using the formulas shown below, based on the Kubelka-Monk algorithm.

1. Calculate the gloss/matte specular correction factor (the specular difference between Everwhite matte and Everwhite gloss tiles):

$$\alpha = \frac{\sum_{i=1}^{n}\left(R_{ew\text{-}matte} - R_{ew\text{-}gloss}\right)}{n}$$

where

R = reflectance value

n = number of wavelengths viewed.

2. Adjust the single-sheet readings over the gloss and black tiles:

$$R'_{over\text{-}gloss} = \frac{R_{over\text{-}gloss} - \alpha}{k_2\left(R_{over\text{-}gloss} - \alpha\right) + \left(1 - k_1\right)\left(1 - k_2\right)}$$

$$R'_{over\text{-}black} = \frac{R_{over\text{-}black} - \alpha}{k_2\left(R_{over\text{-}black} - \alpha\right) + \left(1 - k_1\right)\left(1 - k_2\right)}$$

where

k_1 and k_2 are correction factors determined by and proprietary to HunterLab.

3. Adjust the Everwhite gloss tile:

$$R'_{ew\text{-}gloss} = \frac{R_{ew\text{-}gloss}}{k_2 R_{ew\text{-}gloss} + (1 - k_1)(1 - k_2)}.$$

4. Define $a = R'_{over\text{-}black} R'_{ew\text{-}gloss}$

   and

   $b = R'_{over\text{-}black} - R'_{over\text{-}gloss} + R'_{ew\text{-}gloss}\,(1 + R'_{over\text{-}black} R'_{over\text{-}gloss})$.

5. Compute unadjusted reflectance at full opacity. For wavelengths where $b^2 - 4a^2 < 0$, set $R'_\infty = 1$. Otherwise,

$$R'_\infty = \frac{-b + \sqrt{b^2 - 4a^2}}{2a}.$$

6. Compute the adjusted reflectance at full opacity:

$$R_\infty = \alpha + \frac{(1 - k_1)(1 - k_2) R'_\infty}{1 - k_2 R'_\infty}.$$

These adjusted reflectance values are then used to calculated tristimulus (color scale) values. Sample data (all C/2°) for paper of various colors and opacities is shown in the table below. The "stack" color measurement from a LabScan XE was used as a standard, then the single-sheet opacity and color-corrected measurements are shown for comparison. The single-sheet samples were measured on a SpectraProbe XE backed first by an Everwhite tile, then with no backing, which simulated a light trap.

Sample	L	a	b	DL	Da	Db	DE	Opacity
#1 Stack	60.69	3.60	16.00					
Single Sheet	51.52	0.19	9.12	-9.17	-3.41	-6.88	**11.96**	45.10
Corrected	62.38	3.05	16.29	1.69	-0.56	0.29	**1.80**	
#2 Stack	94.84	-0.92	3.96					
Single Sheet	67.50	-0.23	-1.10	-27.33	0.69	-5.06	**27.81**	47.05
Corrected	93.61	-1.38	3.57	-1.23	-0.46	-0.39	**1.37**	
#3 Stack	95.33	-0.37	0.22					
Single Sheet	70.94	0.25	-3.31	-24.39	0.61	-3.53	**24.65**	51.42
Corrected	96.19	-2.54	-1.33	0.86	-2.17	-1.55	**2.80**	
#4 Stack	70.33	6.70	39.72					
Single Sheet	58.26	-0.42	29.94	-12.06	-7.13	-9.78	**17.09**	51.98
Corrected	70.40	6.09	40.10	0.08	-0.61	0.37	**0.72**	

Sample	L	a	b	DL	Da	Db	DE	Opacity
#5 Stack	90.78	0.38	-0.08					
Single Sheet	73.97	0.05	-1.54	-16.81	-0.33	-1.46	**16.87**	59.39
Corrected	89.86	0.44	-1.23	-0.92	0.06	-1.15	**1.47**	
#6 Stack	92.31	-10.53	40.31					
Single Sheet	75.72	-10.24	24.81	-16.59	0.29	-15.51	**22.71**	62.53
Corrected	91.38	-10.46	39.43	-0.94	0.07	-0.89	**1.29**	
#7 Stack	72.26	30.57	1.54					
Single Sheet	64.67	15.20	-2.02	-7.58	-15.37	-3.55	**17.51**	68.55
Corrected	72.52	28.78	0.78	0.26	-1.79	-0.75	**1.96**	
#8 Stack	47.95	0.17	-24.97					
Single Sheet	47.64	-0.03	-24.16	-0.32	-0.20	0.81	**0.89**	97.90
Corrected	47.79	0.24	-25.23	-0.17	0.07	-0.27	**0.32**	

Note that the opacity-corrected color values are much closer to the standard values than the single-sheet uncorrected values; the DE values are much smaller. After this opacity correction is applied, a small offset value could also be incorporated, if desired, for even closer correlation with the laboratory stack values.

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