DENSITOMETRY AND CHROMATICITY
THE RIGHT INSTRUMENT FOR THE JOB

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Abstract

A densitometric and colorimetric technique for the comparison of the color characteristic of an ink and paper solid are compared. The measurement parameters used were the densitometer derived hue error and greyness and the CIE L*a*b* chromaticity values of hue angle and chroma.

Statistical calculations are derived from the relevant equipment manufacturers' specifications to indicate possible minimum specification limits for both of the techniques used based on instrument measurement noise. Using commercial ink on paper examples the usefulness of these techniques is demonstrated.

Introduction

Printers are manufacturers. They produce ink on paper images, just as General Motors produces cars or 3M produces Scotch tape, magnetic products, or Matchprint pre-press proof materials.

A good manufacturer insures the quality of the goods he produces by paying special attention to the material he uses as well as his outgoing product. He knows he cannot inspect quality into his final product but must ensure its being there from the beginning. A products beginning is not assembly alone but includes the items or ingredients that go into the assembly of the product, the raw materials if you will.

Among the most important of these raw materials is the ink set used. If the inks are wrong the product is wrong. The color appearance of the image is the most crucial to the customer. It can mean the difference between a satisfied customer and make goods. Since a quality job is one that satisfies customer requirements, the choice of which ink to be used to match a customer's request or which ink to use as a replacement ink is not a trivial one.

In the 1950's and 1960's, Preucil[1] pioneered the concept of using a densitometer to quantify the color of printing inks. He determined the secondary absorptions or color

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contaminants in a color ink by using densitometer readings of a single printed single ink or overprint color patch through three color filters.

According to this practice an ideal or pure color would have no secondary absorptions and therefore a reading would be obtained from only one of the 3 filters used in the densitometer. Since nothing in the world is pure or absolute including ink color, the densitometer measurements of a single printed color produce measurements from all three densitometer filters. The lowest of the densitometric filter measurements (L) is used to indicate the color secondary absorption that contributes to the greying factor of the ink color. The middle densitometric value (M) is used to indicate the color contamination of the major color and the highest densitometric value (H) represents the major color. The values called Hue Error and Greyness produced by manipulation of these L, M, H densities were assumed to related to how a person saw that color.

During that same period Yule[2] proposed that the international specification proposed by the CIE for color measurement, chromaticity, be used to measure and define color inks. Others including Mauer[3] have also proposed this technique. The instruments to enable such measurements were then bulky, cumbersome, and expensive. Pearson and Yule [4] proposed the conversion of a densitometer to a colorimetric measuring device, the CIE Standard Observer Colorimeter to facilitate this measurement. At that time the techniques for filter manufacturers to produce filters matching the CIE were imprecise and therefore this conversion was not offered commercially. The advanced use of filter production by vacuum deposition and the use of microcircuitry as well as the solid state advances in electronics in the 1980's allow the production of instrumentation to overcome these difficulties. Portable chromaticity measurement devices like spectrophotometers and standard observer devices are now available at low cost and with an ease of operation equal to that of a densitometer. A comparison of the color analysis techniques to those of one type of chromaticity measurement device, a standard observer colorimeter for practical graphic arts in shop use has not as yet been documented. This paper will attempt to compare the results from these devices when used for ink color comparisons.

Experimental

A 3M customer, Litho Specialties of St. Paul, MN, was having difficulty in matching a particular customers yellow containing color sample with seven different printed yellow ink images used in combination with a common magenta and çyan ink. Although the densitometric hue error and greyness values were quite close, the printed ink samples appeared quite different. The measurement evaluations were obtained from Status T density measurements by X-Rite model 309 reflection densitometer from a printed 3M Matchprint Color Test Form containing a stripped in original GATF Color Reproduction Guide. Figure 1 identifies the yellow inks used by Litho Specialties.

Figure 1

Sample #	Ink Type
1	Lustro + Foreign
2	Consol Lustro
3	Lustro Mallard Test
4	K + M Lustro
5	MFC Lustro
6	Lustro Original Ink
7	Corniche Original Ink

Figure 2 details the ink solid densities for all seven of these samples.

Figure 2

Sample #	Y	M	C	K
1	1.04	1.40	1.31	1.94
2	1.07	1.36	1.32	2.08
3	1.27	1.26	1.33	1.91
4	1.00	1.33	1.36	1.83
5	1.10	1.34	1.28	1.79
6	1.09	1.26	1.30	1.90
7	1.10	1.27	1.30	2.00

The following formulas were used to calculate the hue error and grey values.

Hue Error $$\frac{M-L}{H-L}$$

Greyness $$\frac{L}{H}$$

where L, M, and H are the low, medium, and high density readings for a solid color measured through red, green, and blue densitometer color filters.

Although hue error and greyness values have been used for over 20 years, no standard aim points for these measurements are yet available and even more important, no data has been available on how much of a difference between the hue error and greyness values from different ink samples are significant both for human detection as well as for sample to sample instrument measured variation. A psychophysical study of the just noticeable differences to hue error for a standard observer is beyond the scope of this investigation. That investigation can not be instituted without a statistical study of the machine imposed variance of a densitometric color measurement or the variance imposed by a particular chromaticity measurement device.

A computer technique sometimes referred to as "What If" can easily be used to determine what portion of the variance of densitometer and colorimeter measurements relates to the measuring instrument itself.

The manufacturers' most frequently quoted value for density measurement accuracy is + .01 density units. Starting with a set of typical SWOP color density values, calculations were made to statistically compute the hue error and greyness at + .01 density units. The resultant hue error and greyness ranges are listed in figure 3. Per color, note the range of values due to densitometer variation - hue error value of 4 density units or 4% and greyness difference of 2 density units or 2% for the yellow ink measurements.

Figure 3.
Range of Hue Error, Greyness Values Obtained From a SWOP Yellow Density Value ±.01 Density Per Color Filter Measurement

Ink	Hue Range	Greyness Range
Yellow	8.2-12.4 (Δ4.1)	3.9-5.9 (Δ2.0)
Magenta	36.9-40.0 (Δ3.1)	6.4-7.9 (Δ1.5)
Cyan	16.0-19.8 (Δ3.8)	17.6-19.4 (Δ1.8)

Δ = delta or difference

Applying these ranges obtained from the seven yellow inks evaluated (figure 4), one can see that the differences in hue error and greyness can be attributed to densitometer variation. The hue error value differences are not statistically significant and are due to densitometer noise. The greyness values are equal to the noise value for yellow ink measurements.

Figure 4.

Sample #	Hue Error	Greyness
1	4.26	1.05
2	5.21	3.03
3	6.78	0.84
4	6.67	2.17
5	5.00	1.96
6	5.05	1.98
7	5.05	1.98
range	4.26-6.78 (Δ2.52)	0.84-3.03 (Δ2.19)
statistically significant range to overcome densitometer noise	(Δ4.1)	(Δ2.0)

Colorimetry

The same GATF targets were measured with a standard observer colorimeter made by the Minolta Company and available as model CR 121.

There are two basic differences between a densitometer and a standard observer colorimeter. First, a densitometer uses a somewhat arbitrary set of filters. A 1987 Taga color workshop presentation entitled "A Green Grocers Approach to Color" by Richard Fisch stressed the need to match the band pass characteristics of densitometer filters to the inks or colors to obtain proper readings. The densitometric filter sets for reflection measurement of photographic dye produced images do not match the variety of inks used. The present defacto standard densitometer filters used for graphic arts purposes do not themselves match printing ink specifications. The standard observer colorimeter filters are specified by the International Commission on Illumination (CIE) and are matched to the color perception of a person or standard observer. The values obtained from these filters will be related to color as perceived by a person.

Second, the output of a densitometer is density which is a log function and the output of the colorimeter is in values which tend to be linear in nature depending on the color transform used. Log values compress data and tend to limit the resolution of the output data.
The same statistical technique to compute the machine variance of the colorimetric values "What If?" were used to produce delta chromaticity values that are significant and not due to machine interference.

The L*a*b* values are listed in figure 5 for the seven yellow process inks as measured by the Minolta colorimeter. L* is the lightness designation, a* being the red-greeness, and b* is the yellow-blueness.

Figure 5.

Sample #	L*	a*	b*
1	90.9	-13.59	96.5
2	89.65	-11.25	96.91
3	89.75	-10.57	109.15
4	89.65	-12.26	92.28
5	89.83	-12.89	99.42
6	90.21	-12.5	99.51
7	89.54	-12.65	98.85

The same "What If?" technique was used for determining colorimeter machine noise as was used for densitometry. Chroma and hue angle was computed for typical samples using these formulas.

hue angle $\quad \arctan \frac{b^*}{a^*}$

chroma $\quad \sqrt{(a^*)2 + (b^*)2}$

Then the manufacturer's specifications of ±0.2 for a* and b* were applied to these chroma and hue angle formulas. From these calculations one could expect a chroma difference of

0.45 and a hue angle difference of 0.2 due to instrument variability for a typical yellow ink. The L*a*b* values for the typical yellow ink colors are detailed in figure 6.

Figure 6.

L*	89.99
a*	12.24
b*	100.06
Range: Chroma	100.58 - 101.03 (Δ 0.45)
Hue Angle	96.87 - 97.07 (Δ 0.20)

The hue angles and chromas of the actual ink samples are listed in figure 7. When the instrument variability is applied to these samples, some of the samples are indeed within instrument variability. Some, however, are definitely outside instrument error.

Figure 7.

Sample #	Hue Angle	Chroma
1	98.02	97.45
2	96.62	97.56
3	95.53	109.66
4	97.57	93.09
5	97.39	100.25
6	97.16	100.29
7	97.29	99.65
Range	95.53 - 98.02 (Δ2.49)	97.45 - 109.66 (Δ12.21)

Visual Analysis

Visual analysis by several individuals independent of the instrument analysis indicated close matches between samples 6 and 7. Samples 1 and 3 were quite different in appearance.

Summary

The densitometer analysis indicates that the seven yellow inks are essentially the same. Or, one can not distinquish sample differences from normal instrument statistical variability.
The colorimetric analysis indicated similarities and differences. The samples that visually indicated similarities did indeed appear similar - when the values indicated differences the visual appearance was different. The final criteria of course is visual inspection. Visual inspection, under correct illumination of course, indicates s better correlation to chromaticity measurements than densitometry between the ink samples.

It is evident that the colorimeter values more closely match that of our visual determinations.

For the purpose of ink matching (to another ink or sample) colorimetry proved to be better than densitometry. For other graphic arts applications one should use the right instrument for the right job.

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