A CONTRIBUTION TOWARDS A STANDARD METROLOGY FOR THE COLORIMETRIC SPECIFICATION OF PRINTING INK COLOR PART II DENSITOMETRY

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ABSTRACT: A previous paper "A Contribution Towards a Standard Metrology for the Colorimetric Specification of Printing Inks" [1] detailed the colorimetric differences in CIE color notation, between proposed standard conditions and illuminants for the two predominant ink color sets.

This presentation is offered as a contribution to the pool of metrology knowledge needed to formulate a colorimetric/densitometric standard for graphic arts inks The samples used for this examination are those distributed as representing the US (SWOP) Specification for Web Offset Publication ink set and the International Ink Set (ISO 2846) [3].

Traditionally, an abridged colorimeter, the densitometer is used as an in-process and quality control device to characterize graphic arts ink-on-paper images. In the graphic arts, information on color quality is needed in at least two different points in the print reproduction process. One of these is in raw materials, checking to insure that the proper color ink has been obtained and will be used. Another is in process quality control checking at the printing stage to ensure print consistency and proper ink film thickness. In the past,densitometry has been used to satisfy both of these needs. However ink sets with very different visual color appearance may produce the same color density values [2]. To insure consistent color printing, the values obtained from a densitometer must directly correlate with the visual color characteristics of the standard ink sets.

Densitometers for use in the graphic arts can be purchased with three different filter sets. Each of the sets has its supporters and detractors. It is the intent of this paper to compare data outputs from these densitometer filter sets to each other and to densities derived from spectrophotometric measurements.

Using samples from the Munsell Color Notation Atlas, this paper will also explore the ability of the various densitometer filter responses and colorimetry to discriminate between closely spaced color ink on paper images

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INTRODUCTION:

In many parts of the world, an abridged colorimeter, the three filter densitometer, is used to provide qualification of colored raw materials as well as for in-process control in the reproduction steps. However, ink sets with different color appearances may produce the same densitometric values. Attention to the densitometer illuminant optical filtration, and photosensor response [4, 5] as well as knowledge of the match between spectral response of the ink set and the spectral response of the densitometer can reduce errors innate in these measurements.

Spectrophotometric characterization is the most precise method of specifying the color characteristics of the standard printing inks. A previous paper [1] clarified the color differences apparent in commercial and international ink sets under select changes in spectrophotometer set up conditions.

This paper will further assist in the specification process by comparing the differences between the three standard densitometer filter sets (all three are detailed in ANSI/ISO PH 2.18 and DIN 16536), when used to measure common ink on paper samples.

EXPERIMENTAL

Materials and Conditions

SAMPLES

It should be noted that the samples used in this work are different from the those used in Part I, the first paper in this series [1]. An up to date ISO sample printed on a standard stock is employed in this paper.

The physical samples in this study are representative specimens of the July 1989 U.S. Specifications Web Offset Publications (SWOP) Hi-Lo Color Reference (from the International Pre Press Association) and the International Standards Organization ink set ISO 2846 as reproduced in the sample SNV 666212.

The physical size of the color patches in both samples [1.75 cm x 4.0 cm in the case of SWOP and 3cm x 3cm in the case of the ISO samples] as compared to the sample aperture size of the densitometers [3.6 to 5mm] contributes to positioning difficulties when different densitometers are used to read the same sample. This difficulty does not occur in our spectrophotometric readings since all calculations are made from a single reading.

Selected samples from the Munsell Color Atlas are also included in this study. The [density based] Hue -Error responses will be graphically compared to the CIE L*a*b* Hue Angle values to test the hypothesis that both of these metrics are related to visually uniform color differences. These samples are also used to test the hypothesis that the Hue-Error [density] based calculation from any one particular set of filter response is best suited to predict small changes in color appearance,

EQUIPMENT

SPECTROPHOTOMETER:
The Gretag SPM 100, available from Gretag, Regensdorf, Switzerland was chosen because of its ability to provide spectrophotometric, colorimetric and densitometric responses from a single reading. The 45/0 geometry is in keeping with the previous papers conclusion that 45/0 geometry more closely correlates with densitometry than diffuse geometry specular included or excluded.

To insure consistency, the standard spectrophotometer set up conditions are the same as those chosen in the earlier contribution. They include:

1. 45/0 Geometry
2. 5000 Kelvins illumination
   to match those standards detailing graphic arts viewing conditions [6]
3. 2 Degree CIE 1931 Standard Observer
   to recognize that graphic arts images are usually composed of complex small color areas which best correlate to this condition [7]
4. Black Backing behind the sample [8] (Munsell N2)
   to recognize that graphic arts images are usually printed on both sides of a paper and some cross talk can occur

DENSITOMETER
Commercial Densitometers are sold with different filter sets. In densitometry, optical filtration is used to separate a color image from its background. The term band-pass, when applied to optical filtration, refers to the spectral window - ie, the range of wavelengths passed by the filter. A 20nm filter allows a 20nm wavelength band-pass. A spectral range of from 380 to 700nm would contain 16 equally spaced 20nm windows. The peak, or position of the window, describes the position of the band-pass in relation to the total spectrum. For relative work , such as percent dot area coverage by density, the band pass requirements should have some relationship to the paper and ink color spectrophotometric curves.

The commercial densitometers employed include:
X Rite 418 Status "T"
Gretag 186 Status "T"
Gretag D 186 DIN
Gretag D186 NB

The X-Rite Status "T", available from X-Rite Grandville MI., and Gretag 186T system (including filtration) response are covered by the ANSI/ ISO PH 2.18 photography specification, the other Gretag densitometers under DIN documentation. Since the PH 2.18 standard is written in terms of system response (illumination, filter, optics, photosensor) and the DIN 16536 specification is in terms of Wratten Filter values, some differences may occur when direct computations of density values are made.

The densitometer apertures were 5mm for the Gretag devices and 3.7mm for the X-Rite 418. The X-Rite device uses 0/45 geometry, while the others use 45/0. This physical difference may also affect the resultant data.

STUDIES

Unless otherwise noted, the values reported will follow graphic arts tradition and be reported as base density excluded.

Three different studies are included in this contribution.

1. Graphic depiction of the commercial densitometric responses with spectrophotometric characteristics of the standard ink set .
2. Comparisons of the density outputs of different measuring instruments.
3. The ability of the metrics Hue-Error and Hue Angle to discriminate between color samples that differ slightly in uniform color space.

STUDY 1
THE RELATIONSHIP BETWEEN THE SPECTROPHOTOMETRIC CHARACTERISTICS OF THE STANDARD PRINTING INKS AND DENSITOMETER RESPONSE

Introduction:

Densitometry does not measure color. It provides a measure of the energy obtained from light falling on a non-equal energy photosensor modified by a arbitrary colored filter.

Continuous tone photographic reflection images consist of a reflective base covered completely by a image carrier or colorant. Variations in density follow Beer's Law.

When measuring continuous tone images, using densitometry, a light beam is directed through the continuous layer onto the base. Some portion of the light is absorbed by the image layer and the rest reflected off the base back through the continuous layer onto the photosensor.

A graphic arts halftone reflection image consists of reflective base covered by a pattern of discontinuous images. When measuring the graphic arts halftone pattern light is directly incident onto the reflective support and the image pattern. Increasing image area (percent dot area) coverage does not follow Beer's Law. In the Graphic Arts this phenomena is called Additivity Failure.

Densitometer filter band pass characteristics can also be important. If the densitometer spectral response is such that a portion of the image colorant spectrum falls within the densitometer band pass the extra or stray light can influence densitometer output. Therefore halftone densitometry must be treated differently than continuous tone densitometry.

Apriori, the reflection densitometer user believes that the device measures the actual density of the ink or colorant on its reflective support as depicted in Figure 1. This figure indicates the different blue filter/system responses of densitometers and also indicates the Density vs Wavelength spectrophotometric response of a yellow inks.

However, as indicated reflection densitometers measure the amount of light being reflected (percent reflection) off a substrate. If the substrate contains a graphic arts halftone color image, light is absorbed by the color image as well as the arts halftone color image, light is absorbed by the color image as well as the substrate. The densitometer reflectance response is modified by that absorption. The additional unwanted absorption can provide a source of error. The modified reflection data (%R) to the device is then mathematically converted to Density (Density = Log_{10} 1/R). The densitometer does not directly measure the image but only the reflectance of the paper as modified by the image.

Scope:
This study graphically depicts the relationship between the different commercial densitometer filter/system responses and the two standard ink sets.

RESULTS:
Figures 2-4 show the three densitometer responses to Y, M, and C SWOP inks, and the three densitometer responses to the Y, M, and C ISO inks. All measurements include the base paper.

Since the densitometer does not directly measure the image but only the reflectance of the paper as modified by the image, the best filter response must be one that does the best job of isolating the base reflection from that of the color image. The band pass of the Status "T" blue densitometer response includes a portion of the both the SWOP and ISO yellow ink spectrums. The base and color image data from this filter set is convoluted or intermixed. Such convolution can cause erroneous percent dot area values.

The Blue cut off characteristic that differentiates the Blue Status"T" response from the Blue DIN 16536 response ameliorates this condition and therefore the Blue DIN 16536 densitometer filter is preferred over the Status "T" response. Both Green Filter and the Red response of the Status "T" and DIN 16536 are equally good .

The 20nm band pass characteristics of the DIN 16536 Narrow Band densitometer set provides the best isolation of the base and color image for both ink sample sets. Such small band pass characteristics are preferred for the measurement of ink percent dot area coverage.

Densitometers are often used to characterize differences between replacement inks (for a in-shop standard) or to detect small ink changes throughout a set period. Small band pass characteristics appear to minimize the Hue-Error calculation differences between different ink samples and therefore may not be useful in the determination of this metric. Study 3 attempts to clarify the color difference ability of Hue Error for this application. An assumption is made that the Hue-Error metric can provide uniform differences between colors having a uniform color space difference. Study 3 attempts to clarify the color difference ability of the Hue Error metric for this application.

STUDY 2
COMPARISONS OF THE DENSITY OUTPUTS OF DIFFERENT MEASURING DEVICES.

INTRODUCTION:

Comparisons of the responses of ANSI and DIN densitometers for these samples have not been reported in the Graphic Arts literature. It is also important to understand the relationship between spectrophotometer-based density and values produced by commercially available densitometers.

SCOPE:

Four different densitometers [X-Rite (Status T), Gretag (Status T), Gretag DIN, and Gretag DIN NB] were used to measure two ink sets (SWOP HI-LO and ISO 2846). These values are compared to densities for these same images as determined by spectrophotometry.

RESULTS:

Tables 1 and 2 show the responses of the spectrophotometer and densitometers to the SWOP colors and the ISO colors. Table 1 lists the density values, Table 2 lists the delta differences in density between spectrophotometric density and commercial densitometry.

Table 2 illustrates the delta density values obtained from commercial densitometers as compared to the spectrophotometer computed filter/system densities.

DISCUSSION

This test measures the difference between densities from a commercial densitometer and those obtained by applying mathematics to a spectrophotometric readings of the same samples. Densitometric value whether obtained directly from densitometry or by spectrophotometric determination are <u>not</u> color values.

An average density difference of about 0.23 exists between the SWOP Blue Status"T" densities and that of the same samples analyzed by the DIN filtration. Differences.of about 0.30 between Status"T" and DIN response for the ISO samples are also part of the same phenomena. The convolution of the Blue portion of the yellow inks spectrophotometric response with that of the base imposes a false value when zeroing to the base. The minimum of the cross talk between the base and color image allows the DIN value to be higher. Differences for the other color images amount to about 0.05.

The differences between densitometers and spectrophotometry are influenced not only by the instruments themselves but by positioning differences on the measured samples. When such factors are compensated for the instrument differences appear to be about ±0.02 as reported in the literature. Blue Filter DIN NB and spectro-determined NB densities differ by 0.03-0.05 units. The delta difference between the commercial DIN NB and computed NB values exhibited are possibly due to the difference between a [physical] narrow band optical filter whose peak falls between the wavelength sampling band pass of the spectrophotometer.

The delta density values obtained from a comparison of spectrophotometric determined density and that delivered by commercial devices is a measure of the differences between an absolute density determination based on the integration of illuminance, standard observer and densitometer filter response and commercial three filter densitometry. Again the sample uniformity modifies this response. In general the ± 0.02 densitometer variability as well as a position variability of about ±0.04 seems to account for the variability differences. Since each instrument was calibrated on its own white calibration plaque, errors in the original calibration of these plaques can also account for small differences between instruments.

This data indicates that the density readings delivered by commercial devices are within experimental error to those derived from a spectrophotometer.

STUDY 3
A GRAPHIC STUDY OF THE ABILITY OF THE DENSITY, HUE-ERROR AND GREYNESS METRICS AND CIE L*a*b* HUE ANGLE METRIC TO DISCRIMINATE BETWEEN (MUNSELL COLOR ATLAS) SAMPLES THAT DIFFER SLIGHTLY IN UNIFORM COLOR SPACE.

INTRODUCTION:
Densitometers are usually used to describe the color differences between a set or target ink value for a press run.and the production samples. The assumption has been made that such density values and the Hue-Error and Greyness metric can indicate the color and direction of hue shifts. Assumptions are also made that uniform changes in ink colorants will be noted in a uniform manner when using this metric.

SCOPE:
The CIE uniform color space system for measuring color differences and the L*a*b* Hue Angle metric are satisfactorily used in other industries as a consistent metric. Graphic means will be used to compare the Hue-Error, Greyness and Hue Angle metrics for printed ink on paper samples. Ink on paper samples encompassing a section of uniform color space. Munsell Atlas samples of 10H V=6 are analyzed using the commercial densitometers and filter responses under study. The metrics Hue-Error and Greyness computed from these are used to draw GATF Color Circle Diagrams [9]. These Hue-Error GATF Color Circle Diagrams are compared to CIE L*a*b* Hue Angle plots. All of the data were accumulated through spectrophotometry. All the values were calculated using base-excluded technique.

RESULTS:
The color density Hue-Error and Greyness values obtained from these calculations are included in the Appendix. The Appendix also lists the Hue Angle calculations.

Figure 5 to 7 illustrate the Hue- Error GATF Color Circle Diagram computed from the Munsell Altas 10H v=6 samples. These were obtained by calculation of the various "filter" responses as densities using spectrophotometry.

Figure 8 illustrates the CIE L*a*b* Hue Angle diagram computed from measuring the Munsell Atlas samples of 10H V=6 samples.

These uniformly distributed color samples as expected indicates uniform color distribution of the samples in a circular manner with the outer extremes still exhibiting uniformity and discrimination.

The CIE color space diagram cannot be used for plotting Hue-Error. Since these samples are not a full three-color ink set, the GATF Color Circle plot was used. GATF Color Circle graphs indicate no distribution that suggested a uniform difference between samples.

Three-filter densitometry, no matter what filter response or calculations used, does not produce information on the color difference or degree of change needed for uniformly distributed color standards. It is concluded that this metric affords no reliable way to determine changes as indicated by the lack of a uniform output from this data.

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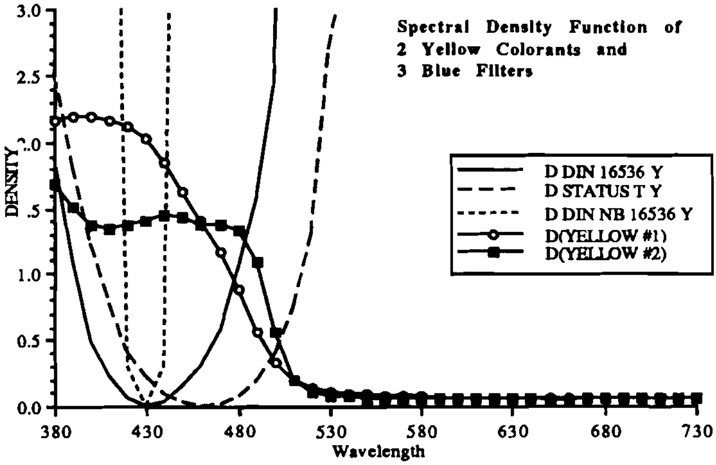

Figure 1

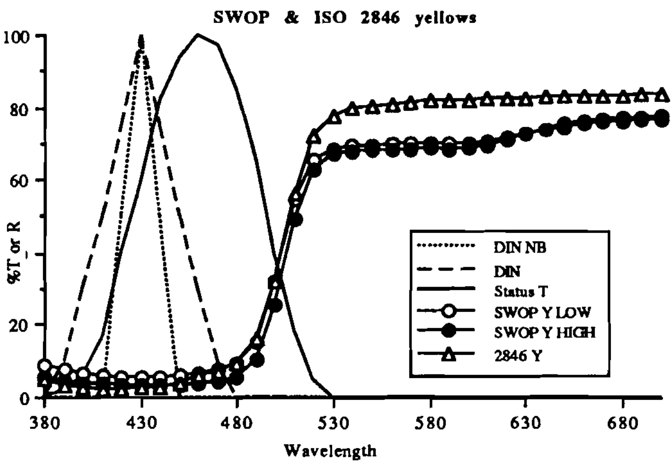

Figure 2

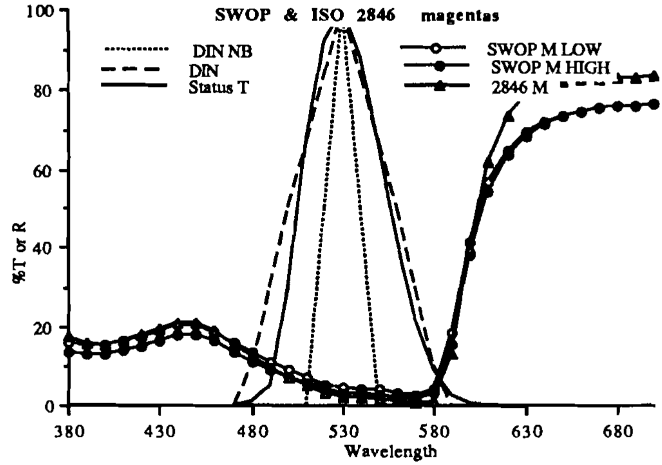

Figure 3

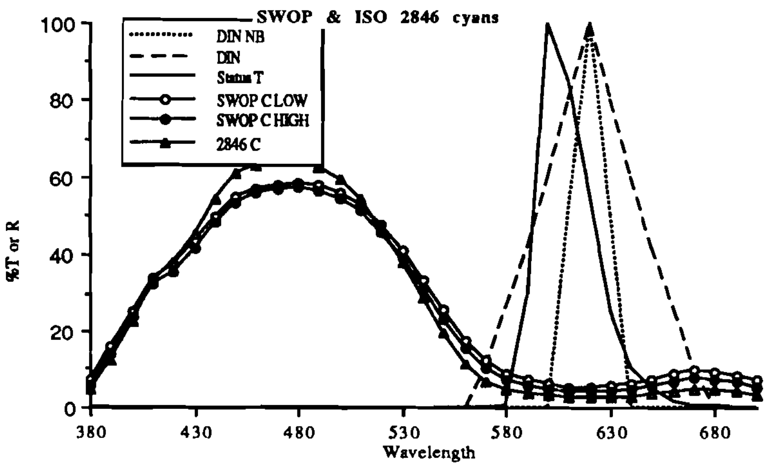

Figure 4

Table 1
MAJOR FILTER DENSITIES

		GRETAG SPECTRO-PHOTOMETER	GRETAG DENSITOMETERS	X-RITE DENSITOMETERS
SWOP HI COLOR REFERENCE				
YELLOW	STATUS "T"	0.94	0.93	0.88
	DIN	1.21	1.16	NA
	DIN NB	1.24	1.27	NA
MAGENTA	STATUS "T"	1.31	1.35	1.33
	DIN	1.34	1.37	NA
	DIN NB	1.39	1.42	NA
CYAN	STATUS "T"	1.22	1.26	1.22
	DIN	1.25	1.27	NA
	DIN NB	1.28	1.28	NA
BLACK	STATUS "T"	1.44	1.47	1.45
	DIN	1.44	1.48	NA
	DIN NB	1.44	1.49	NA
SWOP LOW COLOR REFERENCE				
YELLOW	STATUS "T"	0.77	0.77	0.74
	DIN	0.97	0.97	NA
	DIN NB	1.00	1.07	NA
MAGENTA	STATUS "T"	1.15	1.20	1.15
	DIN	1.17	1.21	NA
	DIN NB	1.22	1.25	NA
CYAN	STATUS "T"	1.03	1.08	1.04
	DIN	1.05	1.08	NA
	DIN NB	1.09	1.10	NA
BLACK	STATUS "T"	1.34	1.36	1.35
	DIN	1.34	1.39	NA
	DIN NB	1.34	1.42	NA
ISO 2846 COLOR REFERENCE				
YELLOW	STATUS "T"	0.95	0.940	0.89
	DIN	1.44	1.420	NA
	DIN NB	1.49	1.430	NA
MAGENTA	STATUS "T"	1.47	1.530	1.46
	DIN	1.50	1.540	NA
	DIN NB	1.61	1.640	NA
CYAN	STATUS "T"	1.51	1.520	1.48
	DIN	1.53	1.490	NA
	DIN NB	1.55	1.540	NA

Table 2
DENSITY DIFFERENCES
BETWEEN DEVICES...Ref.SPECTROPHOTOMETER

		GRETAG DENSITOMETER	X-RITE DENSITOMETER
SWOP HI COLOR REFERENCE			
YELLOW	B STATUS "T"	0.01	0.06
	B DIN	0.05	NA
	B DIN NB	-0.03	NA
MAGENTA	B STATUS "T"	-0.04	-0.01
	B DIN	-0.04	NA
	B DIN NB	-0.03	NA
CYAN	B STATUS "T"	-0.04	0.00
	B DIN	-0.02	NA
	B DIN NB	0.00	NA
BLACK	B STATUS "T"	-0.03	-0.01
	B DIN	-0.04	NA
	B DIN NB	-0.05	NA
SWOP LOW COLOR REFERENCE			
YELLOW	B STATUS "T"	0.00	0.03
	B DIN	0.00	NA
	B DIN NB	-0.07	NA
MAGENTA	B STATUS "T"	-0.05	0.00
	B DIN	-0.04	NA
	B DIN NB	-0.03	NA
CYAN	B STATUS "T"	-0.05	-0.01
	B DIN	-0.03	NA
	B DIN NB	-0.02	NA
BLACK	B STATUS "T"	-0.02	-0.01
	B DIN	-0.05	NA
	B DIN NB	-0.08	NA
ISO 2846 COLOR REFERENCE			
YELLOW	B STATUS "T"	0.01	0.06
	B DIN	0.02	NA
	B DIN NB	-0.06	NA
MAGENTA	B STATUS "T"	-0.06	0.01
	B DIN	-0.04	NA
	B DIN NB	-0.03	NA
CYAN	B STATUS "T"	-0.01	0.03
	B DIN	0.04	NA
	B DIN NB	0.01	NA

GATF Color Circle

Munsell Uniform Color Space Samples 10H V=6

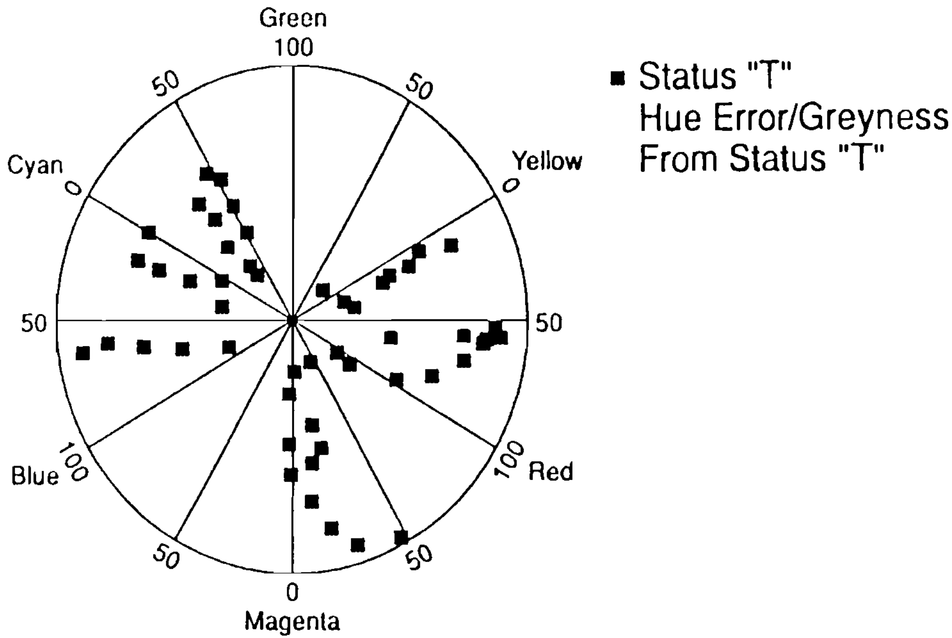

FIGURE 5

GATF Color Circle

Munsell Uniform Color Space Samples 10H V=6

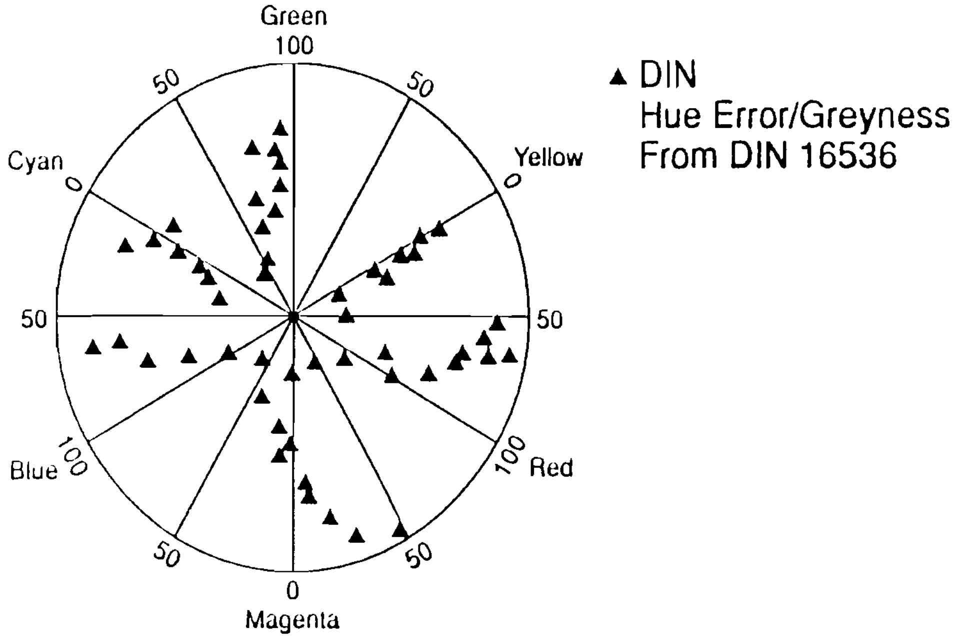

FIGURE 6

GATF Color Circle

Munsell Uniform Color Space Samples 10H V=6

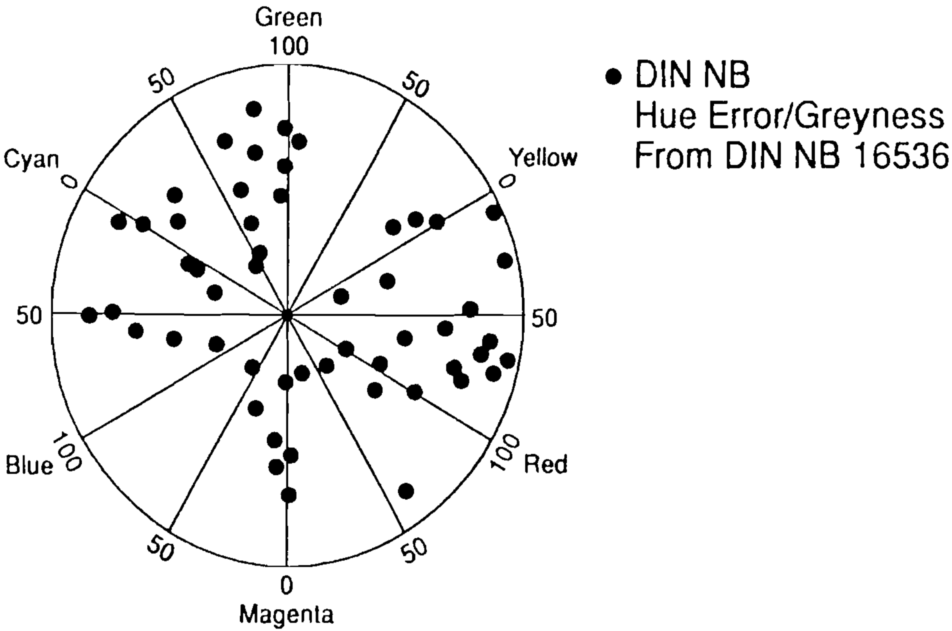

FIGURE 7

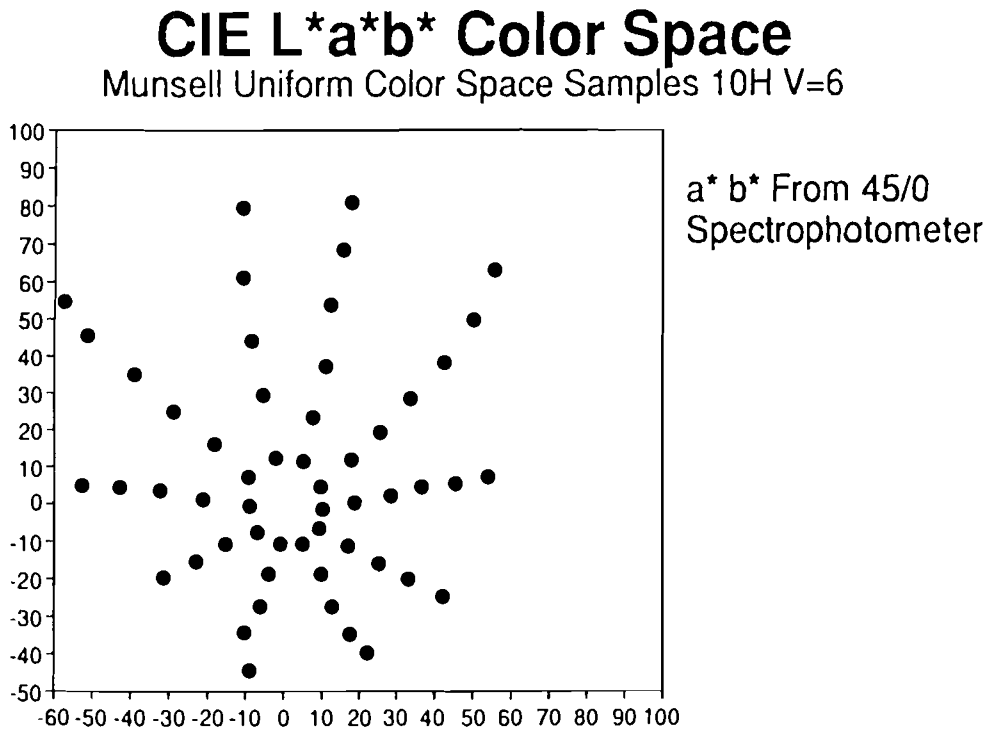
CIE L*a*b* Color Space
Munsell Uniform Color Space Samples 10H V=6
a* b* From 45/0
Spectrophotometer
100
90
80
70
60
50
40
30
20
10
0
-10
-20
-30
-40
-50
-60 -50 -40 -30 -20 -10 0 10 20 30 40 50 60 70 80 90 100

FIGURE 8

Appendix 1

Status "T" Hue Error	Status "T" Grey-ness	DIN NB 16536 Hue Error	DIN NB 16536 Grey-ness	DIN 16536 Hue Error	DIN 16536 Grey-ness	CIE L*a*b* a*	CIE L*a*b* b*
84.51	76.41	50.22	72.37	76.26	78.12	9.00	3.49
95.75	56.70	66.67	51.30	92.81	58.94	17.19	11.07
99.14	41.44	70.53	35.88	97.90	43.72	25.10	18.75
96.13	28.61	76.30	24.54	95.75	30.35	32.93	28.04
92.35	17.70	28.21	14.71	91.45	18.53	41.59	37.79
88.09	10.19	86.69	7.70	86.64	10.25	49.31	48.98
79.72	4.58	97.12	2.19	77.29	3.83	55.57	62.72
57.87	72.46	69.42	74.63	56.92	73.90	4.17	10.54
51.23	52.82	58.12	53.91	48.57	53.86	7.12	23.33
46.00	39.05	50.24	39.18	42.70	39.35	10.18	37.00
38.21	28.15	40.08	27.79	34.77	27.99	11.90	53.46
33.99	21.46	35.12	20.79	30.43	21.02	15.13	68.33
30.31	16.32	31.19	15.54	26.48	15.69	17.14	81.29
6.97	79.21	9.41	77.58	4.19	79.25	-3.11	11.58
5.47	60.52	9.10	57.34	0.47	61.23	-7.21	28.26
4.57	48.04	7.52	44.77	0.33	48.71	-9.99	43.91
2.38	39.38	5.87	36.25	0.89	38.93	-12.26	60.58
4.27	29.58	2.30	29.00	0.24	29.94	-12.39	79.46
88.05	82.89	79.41	75.32	76.96	77.55	-10.73	6.58
84.69	70.99	69.53	59.96	66.21	62.09	-19.79	15.79
87.24	59.35	69.36	46.06	65.59	49.16	-30.21	24.27
83.21	47.42	60.34	33.38	55.57	37.97	-40.37	34.24
84.68	38.21	68.51	25.22	61.78	30.14	-52.14	45.58
76.78	31.20	59.05	17.06	53.90	24.17	-58.71	55.20
12.62	76.13	26.93	72.16	27.62	74.66	-10.42	-1.62
23.62	58.61	45.98	53.09	41.28	56.94	-22.77	0.60
24.18	46.80	47.76	41.26	45.45	46.47	-33.48	2.45
25.75	37.43	52.10	31.68	46.97	38.04	-43.90	3.71
22.64	31.87	48.19	26.12	44.60	32.19	-53.06	4.67
16.58	68.90	10.86	66.84	13.38	69.19	-8.23	-7.98
9.30	52.68	3.19	52.20	2.78	55.63	-17.06	-11.64
9.09	39.36	6.89	39.95	0.75	44.80	-24.75	-16.20
8.54	30.11	12.27	31.83	4.15	37.08	-33.16	-19.83
42.99	70.45	44.22	66.68	48.38	70.21	-1.81	-11.15
36.02	51.82	33.95	49.61	40.65	52.88	-4.99	-18.79
33.49	35.09	30.49	33.56	38.45	36.85	-7.35	-27.47
30.61	22.52	24.33	24.93	31.13	26.29	-11.83	-34.71
31.27	11.63	25.71	14.84	31.26	15.03	-11.22	-44.99
99.11	80.09	98.79	73.87	99.71	77.23	4.66	-10.86
96.72	65.28	95.99	56.99	94.84	61.40	9.32	-19.48
97.63	51.78	99.73	42.54	98.39	47.57	12.88	-27.23
98.01	39.28	99.68	28.17	97.92	33.59	17.81	-35.29
99.46	30.28	97.40	18.16	93.63	23.31	21.82	-40.29
15.80	82.61	31.40	74.25	32.82	79.38	8.77	-7.39
3.02	71.35	17.91	60.22	18.38	66.51	16.40	-12.18
8.39	59.02	6.47	49.12	6.09	55.99	24.78	-16.05
9.58	49.16	3.73	39.13	3.25	46.14	32.65	-20.63
5.49	44.37	0.67	29.08	3.94	33.74	41.45	-25.10
42.54	79.66	11.66	76.57	23.25	81.07	9.62	-2.60
67.01	59.33	51.41	56.63	58.04	60.36	18.31	-0.41
67.21	41.83	50.84	37.43	58.73	42.87	28.06	1.32
70.83	29.80	58.57	24.34	64.50	29.67	36.14	3.47
71.02	19.35	61.75	12.08	65.71	17.18	45.30	5.13
71.61	13.36	64.93	3.99	67.30	9.05	53.19	7.05

Data from figures 8, 9, 10, and 11.

Appendix 2

MUNSELL COLOR		STATUS "T" YELLOW	STATUS "T" MAGENTA	STATUS "T" CYAN	DIN NB YELLOW	DIN NB MAGENTA	DIN NB CYAN	DIN YELLOW	DIN MAGENTA	DIN CYAN
10R	6/2	0.495	0.514	0.392	0.470	0.544	0.394	0.479	0.505	0.395
10R	6/4	0.584	0.594	0.337	0.553	0.660	0.338	0.560	0.577	0.340
10R	6/6	0.665	0.669	0.277	0.627	0.773	0.277	0.634	0.641	0.280
10R	6/8	0.799	0.758	0.223	0.738	0.899	0.211	0.743	0.721	0.226
10R	6/10	0.905	0.848	0.160	0.864	1.019	0.150	0.867	0.806	0.161
10R	6/12	1.058	0.944	0.108	1.071	1.159	0.089	1.017	0.895	0.104
10R	6/14	1.252	1.010	0.057	1.223	1.258	0.028	1.222	0.955	0.047
10YR	6/2	0.563	0.498	0.408	0.549	0.507	0.410	0.555	0.493	0.410
10YR	6/4	0.701	0.540	0.370	0.693	0.559	0.374	0.695	0.530	0.374
10YR	6/6	0.874	0.587	0.341	0.877	0.661	0.343	0.875	0.571	0.345
10YR	6/8	1.080	0.601	0.304	1.100	0.624	0.306	0.110	0.581	0.307
10YR	6/10	1.353	0.652	0.290	1.400	0.681	0.291	1.391	0.627	0.292
10YR	6/12	1.564	0.652	0.255	1.648	0.690	0.256	1.637	0.622	0.257
10Y	6/2	0.576	0.465	0.456	0.577	0.448	0.460	0.581	0.466	0.461
10Y	6/4	0.766	0.480	0.464	0.783	0.499	0.479	0.781	0.480	0.478
10Y	6/6	0.952	0.480	0.457	0.984	0.441	0.481	0.978	0.476	0.478
10Y	6/8	1.218	0.497	0.480	1.262	0.457	0.505	1.254	0.488	0.495
10Y	6/10	1.556	0.507	0.460	1.656	0.480	0.507	1.642	0.492	0.495
10GY	6/2	0.509	0.431	0.520	0.565	0.426	0.536	0.559	0.433	0.530
10GY	6/4	0.589	0.418	0.563	0.686	0.411	0.603	0.680	0.422	0.592
10GY	6/6	0.655	0.388	0.621	0.818	0.377	0.683	0.803	0.395	0.662
10GY	6/8	0.741	0.352	0.676	0.978	0.327	0.720	0.959	0.364	0.695
10GY	6/10	0.878	0.336	0.795	1.186	0.299	0.907	1.163	0.351	0.853
10GY	6/12	1.015	0.317	0.853	1.460	0.249	0.964	1.394	0.337	0.907
10G	6/2	0.437	0.421	0.553	0.459	0.416	0.576	0.462	0.423	0.566
10G	6/4	0.451	0.387	0.660	0.525	0.374	0.704	0.514	0.392	0.688
10G	6/6	0.454	0.356	0.760	0.568	0.338	0.820	0.554	0.364	0.783
10G	6/8	0.446	0.312	0.834	0.601	0.283	0.893	0.577	0.327	0.859
10G	6/10	0.469	0.316	0.991	0.677	0.286	1.097	0.643	0.331	1.030
10BG	6/2	0.388	0.417	0.564	0.390	0.411	0.583	0.396	0.420	0.573
10BG	6/4	0.351	0.381	0.667	0.377	0.366	0.702	0.378	0.387	0.680
10BG	6/6	0.294	0.336	0.748	0.348	0.315	0.789	0.342	0.345	0.764
10BG	6/8	0.257	0.308	0.853	0.360	0.285	0.896	0.343	0.321	0.865
10B	6/2	0.362	0.427	0.513	0.345	0.421	0.571	0.357	0.430	0.508
10B	6/4	0.300	0.400	0.578	0.287	0.388	0.583	0.298	0.406	0.564
10B	6/6	0.226	0.366	0.644	0.217	0.348	0.646	0.226	0.376	0.614
10B	6/8	0.164	0.337	0.728	0.184	0.319	0.739	0.186	0.348	0.707
10B	6/10	0.096	0.325	0.828	0.125	0.310	0.845	0.122	0.337	0.811
10PB	6/2	0.360	0.448	0.449	0.335	0.453	0.452	0.364	0.448	0.449
10PB	6/4	0.303	0.464	0.459	0.271	0.475	0.467	0.285	0.463	0.454
10PB	6/6	0.239	0.457	0.462	0.201	0.471	0.472	0.217	0.456	0.452
10PB	6/8	0.183	0.461	0.467	0.135	0.480	0.479	0.154	0.459	0.452
10PB	6/10	0.137	0.451	0.450	0.086	0.473	0.463	0.104	0.447	0.426
10P	6/2	0.400	0.484	0.413	0.371	0.500	0.411	0.383	0.483	0.416
10P	6/4	0.359	0.503	0.363	0.318	0.528	0.355	0.333	0.501	0.364
10P	6/6	0.335	0.536	0.317	0.280	0.570	0.299	0.299	0.543	0.313
10P	6/8	0.306	0.566	0.278	0.237	0.606	0.251	0.260	0.564	0.270
10P	6/10	0.275	0.580	0.257	0.179	0.614	0.182	0.210	0.578	0.195
10PR	6/2	0.447	0.506	0.403	0.418	0.527	0.403	0.429	0.501	0.407
10RP	6/4	0.470	0.542	0.322	0.439	0.556	0.315	0.450	0.539	0.326
10RP	6/6	0.483	0.597	0.250	0.442	0.638	0.239	0.451	0.590	0.253
10RP	6/8	0.506	0.637	0.190	0.465	0.678	0.165	0.474	0.631	0.187
10RP	6/10	0.521	0.680	0.132	0.477	0.719	0.087	0.485	0.677	0.116
10RP	6/12	0.557	0.738	0.099	0.511	0.771	0.031	0.518	0.737	0.067

Data from figures 8, 9, 10, and 11.