GRAY BALANCE DETERMINATION OF ANALOG ELECTROPHOTOGRAPHIC PROOFS BY MEANS OF SPECTROPHOTOMETRIC MEASUREMENT

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Key words: gray, proofing, spectrophotometry

Abstract: In the past, at the Research Lab of the Royal Smeets Offset company in the Netherlands, the quality control of a color electrophotographic analog proof was done visually every six months by three judges evaluating a proof of a gray balance chart. First, the tone reproduction curves of the four-colored proofs were evaluated by densitometry to insure good dot gain reproductions. Then, the nine shades of gray of the proofs (which are composed of fixed percentages of cyan and varied percentages of yellow and magenta) were visually judged against a Kodak gray scale.

This paper reports on research executed in the Winter of 1992 in which a spectrophotometer was used to control the quality instead of the above-mentioned method. Using the L* C* h(ab) system, the average C* values from each gray patch were compared and an aim point gray balance was selected on the assumption that the patch with the least C* values should be gray.

The gray balance curves made by the conventional and spectrophotometric means were compared. It was found that the spectrophotometric method, linked to a computed measuring program (Lotus), is very successful and much faster than the conventional one.

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Introduction

To control the quality of an analog proofing system is a time-consuming process. To do the control, printers at the Royal Smeets Offset company in the Netherlands study the relationship of the different types of paper they use and the dot gain characteristics of the press proofs. Then they control the optical dot gains of their analog proofs so that the proofs yield similar tone reproduction to those of the press sheets. Solid ink densities of the proofs are also checked and tone reproduction curves of the process ink used are drawn in order to compare them with those of the standard set up by the company research team. But that is not enough for high quality printing because the gray balance, which controls the tone reproduction of images, can be disturbed by the fluctuation of dot gain on one of the three colors. The Dutch printers here have strived to control the gray balance by inventing four in-house proofing charts to help check the gray balance of the proofs (see illustrations in appendix 2). The first chart is to compare the color fidelity of high and low key pictures, skin tone pictures, pictures that have a wide range of color gamut and memory colors. (In this case, they use a wooden texture). The second chart is to compare the color gamut of process ink. The third chart takes a close look at the gray balance. This form varies the percentages of cyan into 9 steps: from 11, 22, 33, 44, 55, 66, 77, 88 and 100; and the percentages of magenta and yellow are varied to make 25 patches of three-color halftone overprints for each fixed percentages of cyan. Thus, there are nine groups of halftone overprints and within each group there are 25 patches of different shades of gray. The fourth chart concerns trapping, black printer characteristics and UGRA wedges.

The conventional routine of gray balance evaluation was done visually every six months to control the deviation in the system. After printers made a number of analog proofs of the four test forms, they would measure the solid densities and dot gains of the proofs and draw the tone reproduction curves of cyan, magenta, yellow and black toners of the proofs. A good set of proofs would be selected on the basis of good tone reproduction, correct solid densities and within-tolerance dot gains. The next step was to invite three persons who are experienced in evaluating color reproductions to select gray balance aim-points from the test form number 3. The judges would lay the test form under a standard light source (5000 K) and use a white paper with a square hole on it , which would be the overlay of the test form, in order to compare each gray patch with a selected aim-point of a Kodak gray scale. Nine gray aim-points would be selected by each judge. The average percentages of magenta and yellow for each fixed percentage of cyan would be calculated. Then a gray balance curve of the proof would be drawn in order to be compared with that of the company standard.

This routine seemed to work well because human eyes are very good at comparing colors. However the printers encountered a serious problem; that is, the Kodak gray scale was fading due to the way in which it was stored. It means that their reference of gray might not be reliable any more after a period of time. It was also found that each Kodak gray scale varies spectrophotographically too. The printers do not want to set up a tolerance of the color differences of Kodak gray scales because they think it a research that Kodak should perform. Instead they were looking for another way to do gray balance evaluation without using a Kodak gray scale. Furthermore, the gray balance aim-points by this subjective evaluation method can vary according to the color experience of the judges. There was also the problem of the reliability of the observers; a judge could give different aim-points if he/she had to repeat the evaluation again. Therefore, the printers were trying to find a more objective way of doing gray balance evaluation. They came up with the idea of using a spectrophotometric evaluation. How this was to be done and what had to be done were the questions then. This author had an opportunity to conduct a pilot research to test a spectrophotometer usefulness in doing gray balance evaluation.

Background of determining a gray balance

Field (1988) defines gray balance as: "the values for the yellow, magenta, and cyan that are needed to produce a neutral gray when printed at a normal density. When gray balance is achieved, the separations are said to have correct color balance. Gray balance is determined through the use of a gray balance chart."

In four-color printing, gray can be simulated by printing dots of primary inks, as Kuehni (1983) argued:

> "A particular problem in color photography and graphical printing is posed by colors that cannot be reproduced by the technical process ... The reproduction process can easily cope with low chroma sensations but is incapable, because of lack of suitable colorants, to reproduce the high chroma sensations."

Field (1988) also stated that a color balance can be determined through a gray balance analysis. A gray balance analysis can be done under normal plant printing conditions by printing an image of near neutral grid patterns of yellow, magenta, and cyan dot values. Then the three-color neutral areas will be found by using a halftone gray scale as a reference. The dot values making up these areas will be used in setting up the gray balance requirements of the color separations.

The idea of using a gray balance chart to control color balance is not new. There are a number of existing renowned color control systems which present different gray balance charts in order to help printers control their gray balance. These include the Brunner test form, FOGRA PMS print control strip, Gretag color control strip, GATF compact color test strip, Hartman printing control strip, Japan Printing Academy color control strip, RIT color test strip and System Spectra color control bar (Southworth: 1989). These help printers conduct their own subjective gray balance determination.

Gray balance can be obtained if dot gain percentages are consistent. Felix Brunner demonstrated at Spectrum '83 and in Eurostandard Cromalin that dot gain changes can affect hue and saturation of a color reproduction more than a change of solid ink density (Southworth: 1989). Therefore, dot gain on presses and proofs must be controlled first; then the gray balance values can be determined.

Determining a gray balance conventionally requires visual determination under a standard light source. Human eyes are accepted to be quite accurate in comparing colors. A trained person is required to judge the gray balance values.

Why spectrophotometry?

Different light sources cause what is called metamerism. Apart from light sources, the observers themselves can experience what is called observer metamerism. Billmeyer Jr. and Saltzman (1981) explained that the minor differences in the spectral response curves of the observers, which are generally called anomalies, not color blindness, can result in a mismatch of one pair of colored objects for one observer but a good match for another. Moreover, the saying "to err is a human" seems to be correct since a person with normal color vision can have a problem with color matching when he/she gets older because yellow or brownish pigments in human lenses can accumulate. These pigments prevent some of the incident energy, particularly the short-wave energy, from reaching the retina (Judd&Wyszecki:1975).

A densitometer is a tool to help control the consistency of a press run. It is used to control the relative ink film thicknesses of ink on the press sheets. A densitometer has nothing to do with a psychometric measurement such as measuring color dimensions because different colors can have the same density. A densitometer uses different filters to measure reflectance or transmission of dyes or pigments while a spectrophotometer measures the spectral reflectance or transmittance of objects by using a known wavelength of a standard light source and a known spectral response of a group called standard observers. By using a spectrophotometer, the problem of light source and observer metamerism is solved. In this case we want to measure the overall effect of the three colors, not the ink film thickness, because the gray patch we want to evaluate consists of cyan, magenta, and yellow dots to give an impression of gray or neutral. What we want to know is if the patch reflects all parts of the spectrum equally or not because Judd and Wyszecki (1975) stated that a neutral or grayish color does not select any one part of the spectrum more than another to be returned to the eye of the observer. In this case, a spectrophotometer can be the most appropriate tool.

Theoretical applications

The 1976 CIE LAB is a cube-root formula which is a transformation of the chromaticity diagram. According to the opponent theory (Billmeyer Jr. & Saltzman: 1981), the a* and -a* indicates redness-greenness. The b* and -b* indicates yellowness-blueness. L* indicates lightness. The lightness of a color changes the color gamut of the CIE L* a* b*. For white and black, lightness is 100 (maximum lightness) and 0 (maximum darkness) respectively.

As part of its 1976 recommendation, the CIE also defined the following color terms: metric hue angle, metric chroma and metric saturation. For CIE LAB, the metric hue angle and metric chroma are defined differently than those in the CIE LUV system. (The metric saturation is used in the CIE LUV only) (Billmeyer Jr. & Saltzman:1981). The values are in a psychometric scale which means that the numbers can be handled by all kind of mathematical means (addition, subtraction, multiplication and division). It helps us to compare only one dimension of a color.

The term chroma was coined by Munsell; he defined chroma as "that quality which describes the extent to which a color differs from a gray of the same value" (Billmeyer Jr.& Saltzman:1981). According to this definition, gray has no chroma, therefore it is called achromatic; it is perceived as having both lightness and darkness. Gray is systematically arranged on the achromatic line according to its brightness. (Keuppers:1980).

In a gray balance chart, the brightness of gray is determined by the brightness of the paper and the dot percentages of the three primary colors. The brightness of the gray patches within the nine groups of halftone overprints is assumed to be constant. We want to select the best one of each group to get a nine gradation of gray. Gray has no hue. Hence, we are interested in measuring the chroma value of gray. The chroma in CIE LAB can be obtained from the following (Billmeyer Jr.& Saltzman:1981):

$$C^*_{ab} = (a^{*2}+b^{*2})^{1/2}$$

There is very little difference in how well (or how poor) CIE LUV or CIE.LAB agrees with visual data. The choice of using CIE LAB depends purely on the specification of the spectrophotometer used.

What are the conditions of the spectrophotometric measurements?

The colorimetric values refer to the CIE recommendation 1931 based on the 2 degree standard observer and are given for illuminant D65 and D50 (CECP: 1989). In this research D50 was used because the subjective evaluation is based on light source D50. The spectrophotometric measurement condition should conform to the reality to avoid the problem of light source metamerism.

Methodology

Material

1. K.C. proofs exposed to a set of test chart films by the following conditions:
    1) color sequence: yellow-black-magenta-cyan
    2) paper base: wood containing KNP paper with smooth machine coated surface (sheet-fed quality) 100 gm/m^2
    3) Toners and finishing are according to the specifications of Stork Co.
    4) Controlling the positive microline of UGRA wedges
        - black 10/12
        - cyan 12
        - magenta 15
        - yellow 8
2. A Kodak reflectance gray scale

Equipment

1. A Stork Coulter proofer (analog system)
2. A spectrophotometer Gretag SPM 100
3. A densitometer Gretag D186
4. A standard set of color comparison (a light source and a table)
5. A magnifier 100 x

Method

1. Made a number of proofs from the original films by using standard conditions set up by the company
2. Measured the half-tone and continuous tone scales of each color by using the densitometer and plot tone reproduction curves
3. Selected a set of proofs that produced acceptable tone reproduction curves

4. Measured the proof of test form no.3 (gray balance chart) with the spectrophotometer. The measurement conditions were:
   L* C* h(ab) system
   CIE-Standard light source D50
   CIE-1931 Standard observer (2 degree)
   Absolute white
5. Recorded only the C* values of every percent dot area of cyan, magenta and yellow (each cell was measured five times) as follows:
   5.1 at C=11% and M and Y vary from 5 to 6, 7, 8 and 9 % ; and 3 to 4, 5, 6 and 7% respectively
   5.2 at C=22% and M and Y vary from 10 to 12, 14, 16 and 18%; and 8 to 10, 12, 14 and 16% respectively
   5.3 at C=33% and M and Y vary from 18 to 20, 22, 24 and 26%; and 17 to 19, 21, 23 and 25% respectively
   5.4 at C=44% and M and Y vary from 28 to 30, 32, 34 and 36%; and 27 to 29, 31, 33 and 35% respectively
   5.5 at C=55% and M and Y vary from 38 to 40, 42, 44 and 46%; and 38 to 40, 42, 44 and 46% respectively
   5.6 at C=66% and M and Y vary from 49 to 51, 53, 55 and 57%; and 49 to 51, 53, 55 and 57% respectively
   5.7 at C=77% and M and Y vary from 61 to 63, 65, 67 and 69%; and 61 to 63, 65, 67 and 69% respectively
   5.8 at C=88% and M and Y vary from 73, 75, 77, 79 and 81 %; and 73, 75, 77, 79 and 81% respectively
   5.9 at C=100% and M and Y vary from 84, 87, 90, 93 and 96%; and 84, 87, 90, 93 and 96 % respectively
6. Calculated the average C* values of each cell of gray from 5.1 to 5.9
7. Selected only the cell which gave the least C* values from 5.1 to 5.9. Recorded the percent dot areas of cyan, magenta and yellow that were printed on the cells.
8. Measured the cells from 7. with the densitometer and recorded the percent dot areas of each cell.

9. Plotted a gray balance curve obtained from the spectrophotometric evaluation.
10. Invited three judges to come and compare the test form no. 3 (gray balance chart) with a Kodak reflectance gray scale.
11. Recorded the cells (5.1 to 5.9) which each judge selected and calculated their means.
12. Measured the cells from 10. with the densitometer and recorded the percent dot areas of each cell.
13. Plotted a gray balance curve obtained from the visual evaluation.

Results

From Table 1, the least C* values of each gray balance aim-points are presented. All of the data are presented in the appendix. The measured densities of the aim-points in the high light are a bit less than the standard set-up by the company (see graph Gray Density Curve of K.C. Proof). The percent dot areas of cyan, magenta and yellow which constitute the aim-points are plot against percent dot areas of cyan (see graph Gray Balance Curve of K.C. Proof). The line connects the cyan percentages is, therefore, a straight line. For each percentage of cyan, one could read the percentages of magenta and yellow that make the patch gray.

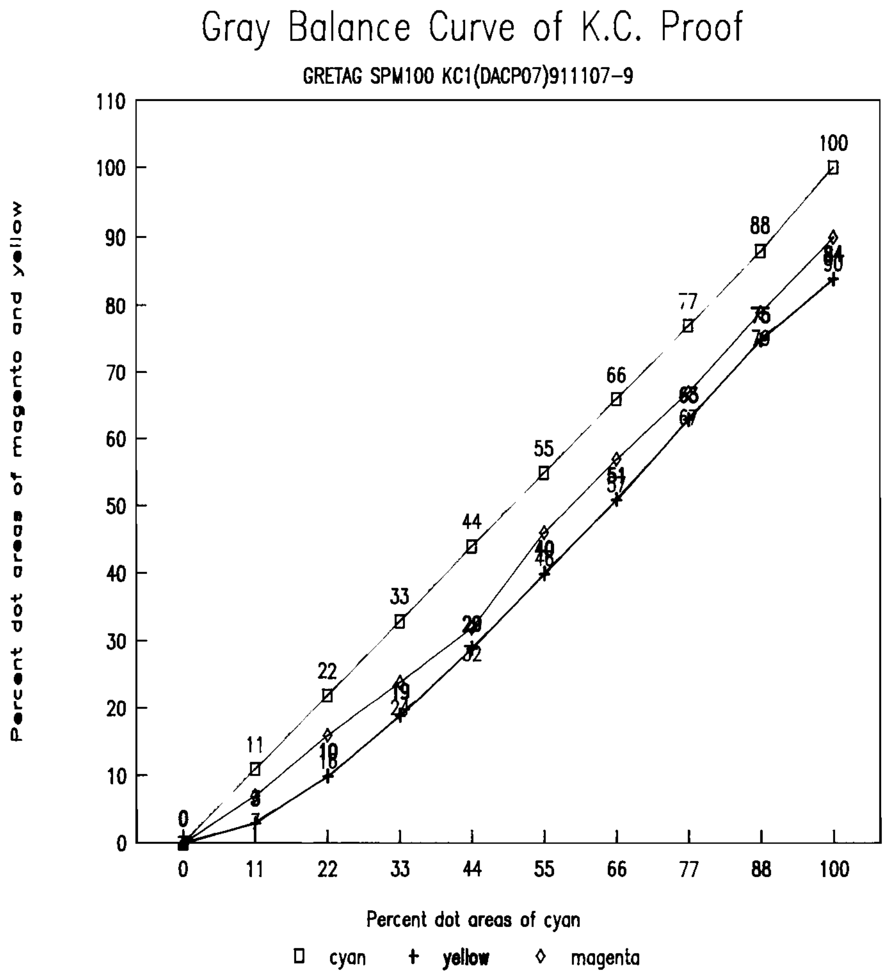
From Table 2, the average gray balance aim-points resulted from the visual evaluation are presented. The measured densities of the aim-points at 33% and 55% cyan are a bit less than the standard set-up by the company (see graph Gray Balance Curve of K.C. Proof). The percent dot areas of cyan, magenta and yellow that constitute the aim-points are also plot against cyan (see graph Gray Balance Curve of K.C. Proof).

Table 3 shows the comparison of the percentages of cyan, magenta and yellow that constitute the aim-points obtained from the two methods. The differences are, in some points, only maximum 2 percent dots. The pattern of the gray balance curve obtained by the two methods is similar.

Table 1

GRAY BALANCE AIM-POINTS RESULTED FROM SPECTROPHOTOMETRIC EVALUATION

% DOT AREA PER COLOR			THE LOWEST C-VALUES						STD. DENSITY OF GRAY (C-M-Y)		MEASURED DENSIY OF GRAY
%C	%M	%Y	1ST. MEAS.	2ND. MEAS.	3RD. MEAS.	4TH. MEAS.	5TH. MEAS.	AVERAGE	MAX	MIN	
11	7	3	0.77	0.76	0.52	1.12	1.05	0.84	0.11	0.09	0.09
22	16	10	0.42	0.40	0.45	0.28	0.84	0.48	0.24	0.20	0.19
33	24	19	0.16	0.17	0.33	0.34	0.07	0.21	0.38	0.32	0.31
44	32	29	1.19	0.94	0.71	1.16	1.06	1.01	0.53	0.46	0.45
55	46	40	0.07	0.34	0.55	0.16	0.08	0.24	0.70	0.63	0.62
66	57	51	0.77	0.66	0.29	0.50	0.79	0.60	0.90	0.81	0.80
77	67	63	0.79	1.49	1.38	0.92	1.60	1.24	1.15	1.01	1.02
88	79	75	1.01	0.67	0.51	0.79	0.80	0.76	1.46	1.24	1.26
100	90	84	0.71	0.64	0.91	0.66	0.39	0.66	1.85	1.50	1.55



Gray Balance Curve of K.C. Proof
GRETAG SPM100 KC1(DACP07)911107-9
Percent dot areas of magenta and yellow
Percent dot areas of cyan
cyan
yellow
magenta

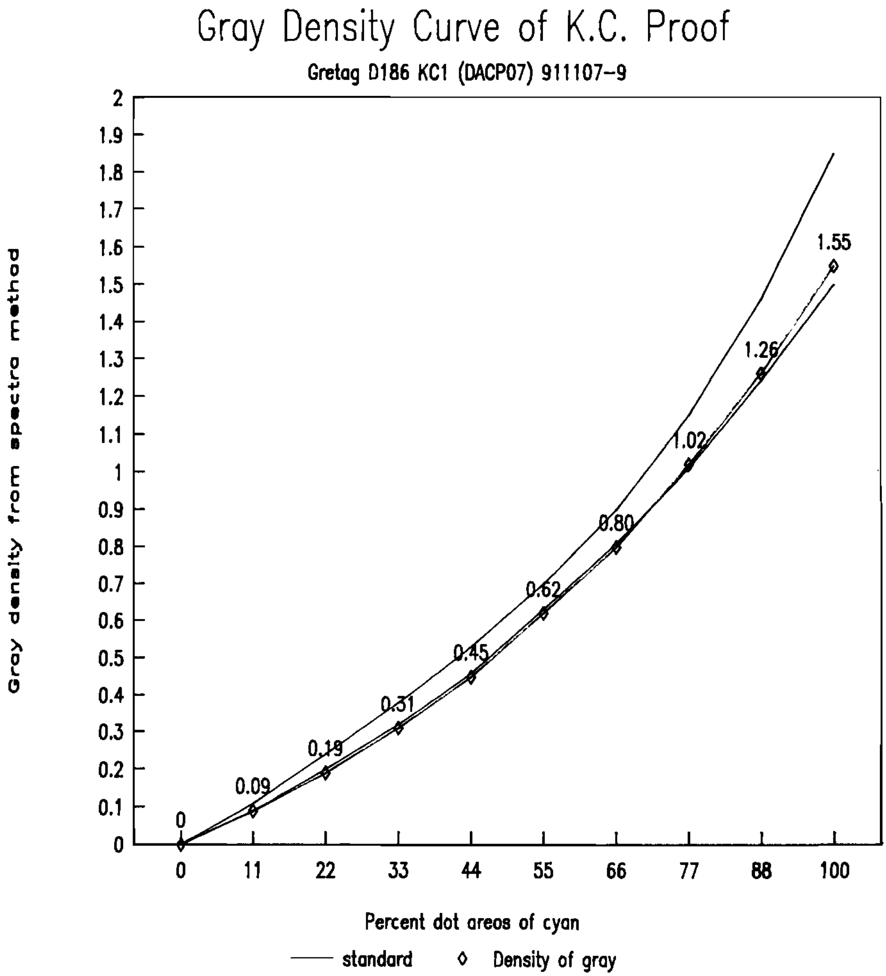
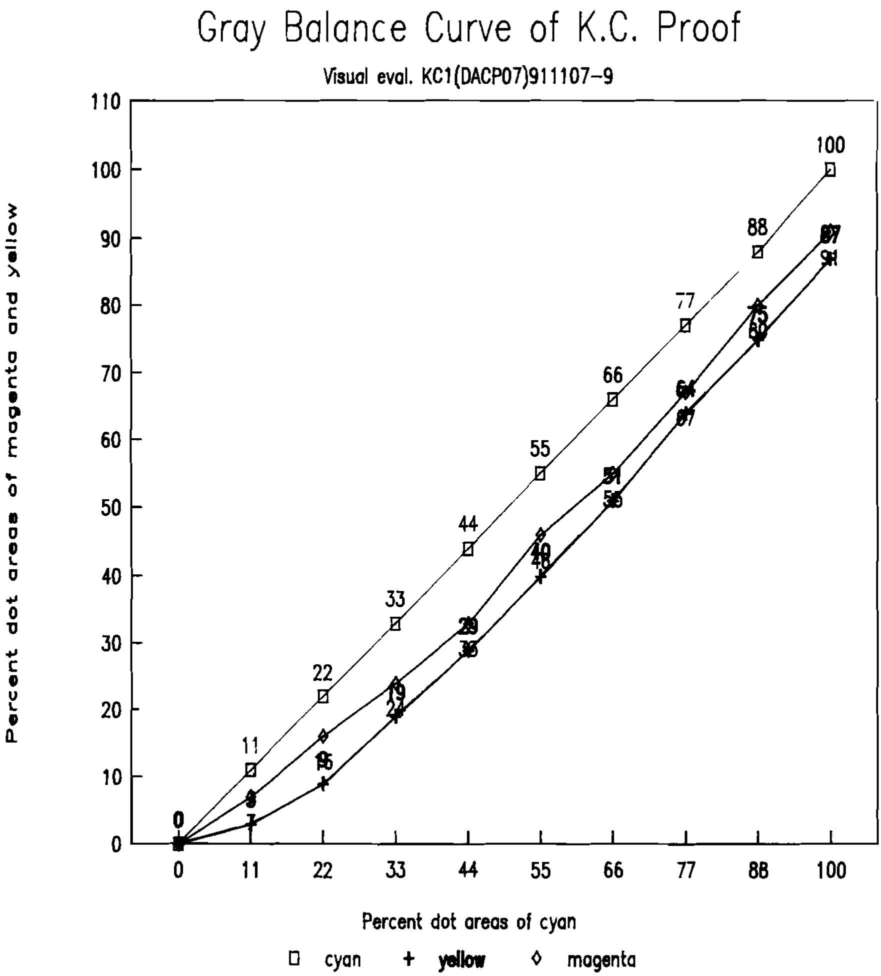

Gray Density Curve of K.C. Proof
Gretag D186 KC1 (DACP07) 911107-9
Gray density from spectra method
2
1.9
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
0.09
0.19
0.31
0.45
0.62
0.80
1.02
1.26
1.55
0
11
22
33
44
55
66
77
88
100
Percent dot areas of cyan
standard
Density of gray

Table 2

GRAY BALANCE AIM-POINTS RESULTED FROM VISUAL EVALUATION

	DENSITY USED FROM KODAK Q16 CARD	1ST JUDGE		2ND JUDGE		3RD JUDGE		AVERAGE		STD. DENSITY OF GRAY (C-M-Y)		MEASURED DENSIY OF GRAY
%C		%M	%Y	%M	%Y	%M	%Y	%M	%Y	MAX	MIN	
11	0.10-0.15	7	3	7	4	7	3	7	3	0.11	0.09	0.09
22	0.20-0.25	16	8	16	10	16	8	16	9	0.24	0.20	0.20
33	0.30-0.40	24	19	24	19	24	19	24	19	0.38	0.32	0.31
44	0.50-0.60	32	29	34	29	34	29	33	29	0.53	0.46	0.47
55	0.60-0.70	46	40	46	40	46	40	46	40	0.70	0.63	0.61
66	0.70-0.80	55	51	55	49	55	53	55	51	0.90	0.81	0.80
77	0.90-1.00	67	65	67	63	67	63	67	64	1.15	1.01	1.03
88	1.10-1.20	79	75	81	75	81	75	80	75	1.46	1.24	1.27
100	1.30-1.40	90	87	93	87	90	87	91	87	1.85	1.50	1.53



Gray Balance Curve of K.C. Proof
Visual eval. KC1(DACP07)911107-9
Percent dot areas of magenta and yellow
Percent dot areas of cyan
cyan
yellow
magenta

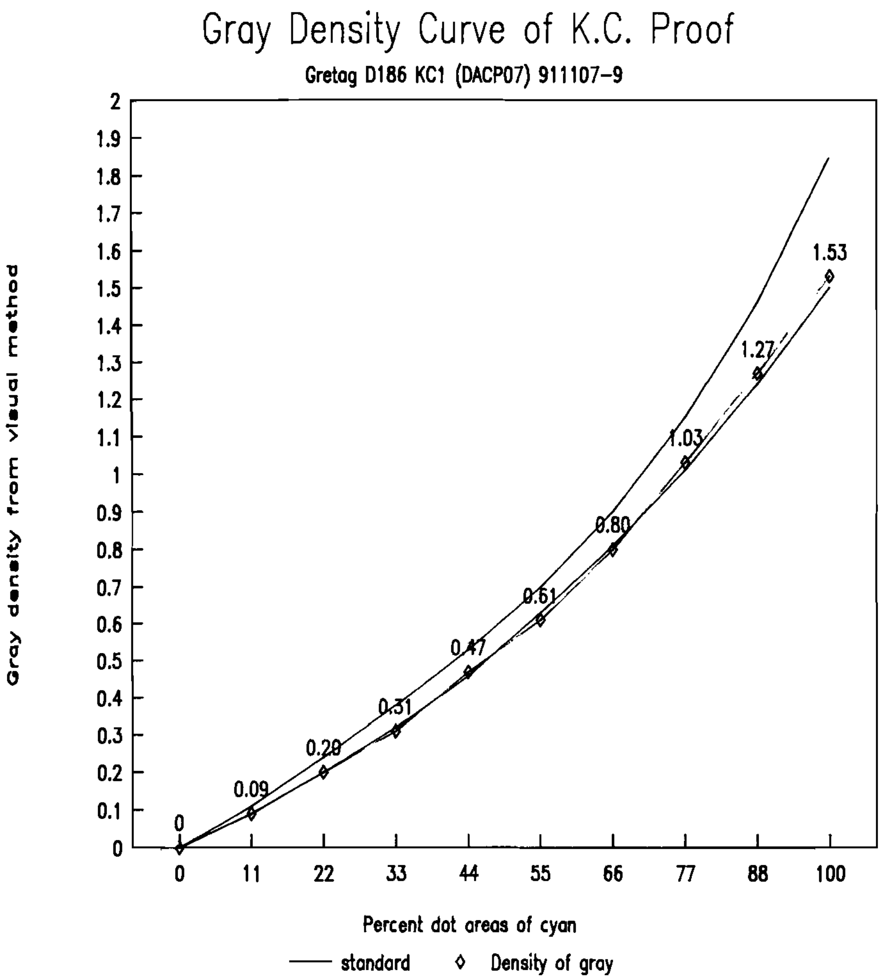

Gray Density Curve of K.C. Proof
Gretag D186 KC1 (DACP07) 911107-9
Gray density from visual method
2
1.9
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
1.53
1.27
1.03
0.80
0.61
0.47
0.31
0.20
0.09
0
0
11
22
33
44
55
66
77
88
100
Percent dot areas of cyan
standard
Density of gray

Table 3

THE COMPARISON OF THE VISUAL AND SPECTROPHOTOMETRIC EVALUATION OF THE GRAY BALANCE AIM-POINTS

Visual Evaluation			Spectrophotometric Evaluation		
%C	%M	%Y	%C	%M	%Y
0	0	0	0	0	0
11	7	3	11	7	3
22	16	9	22	16	10
33	24	19	33	24	19
44	33	29	44	32	29
55	46	40	55	46	40
66	55	51	66	57	51
77	67	64	77	67	63
88	80	75	88	79	75
100	91	87	100	90	84

Conclusions and recommendations

From the results, it can be concluded that a spectrophotographic evaluation of the gray balance can substitute for a subjective evaluation. However, it is time consuming to measure each cell of gray balance five times when using a spectrophotometer (there are 225 cells). A computer program can be used to help this tedious routine. By linking the spectrophotometer to a personal computer and measuring the gray balance with the Lotus measuring program and transferring the data to the Lotus program, one can write an easy program to calculate the average C* values of the cells from the nine blocks and select the cell which gives the least C* values and the percentages of cyan, magenta and yellow that comprise the cell. In this research each cell is measured five times in order to get very precise values of the halftone dots. This compensates for the problems of measurement inaccuracy that might occur due to the aperture of the spectrophotometer and the dot coverages. In practice, it was shown that a three-time measurement also gives good results (correlated to what the judges saw).

A spectrophotometer and a colorimeter can give different results due to the spectral reflectance characteristics in a colorimeter or the accuracy of measurement of the instruments themselves. The concern that using different measurement systems such as L* C* h(ab) or L* C* h (uv) might change the results or not need to be further studied. The change of standard light source and the angle of the standard observers will certainly change the results.

The Process Engineering Division of the Royal Smeets Offset company is now using a spectrophotometer (linked to a personal computer) to determine gray balance instead of using three judges. This author hopes that the results of her research can be helpful to those who are interested in applying a spectrophotometer in the Graphic Arts industry.

Acknowledgments

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Selected Bibliography

Billmeyer Jr., F., and Saltzman, Max

1981 Principles of Color Technology, 2nd. Edition. John Wiley & Sons Inc., New York, pp. 22, 59, 63-64

CECP Document

1989 "European Colour Standard for Multicolour Printing," in European Confederation of Paint, Printing Ink and Artists' Colours Manufacturers' Associations. no. CEI 30-89, p. 5

Field, G.

1988 Colors and Its Reproduction. GATF, Pittsburgh, pp. 334, 341

Judd, D. B., and Wyszecki, Gunter

1975 Color in Business, Science and Industry. John Wiley & Sons Inc., New York, pp. 13, 38

Keuppers, H.

1980 The Basic Law of Color Theory. Du Mont Buchverlag Gmbh & Co., Cologne, pp. 28, 64

Kuehni, R. G.

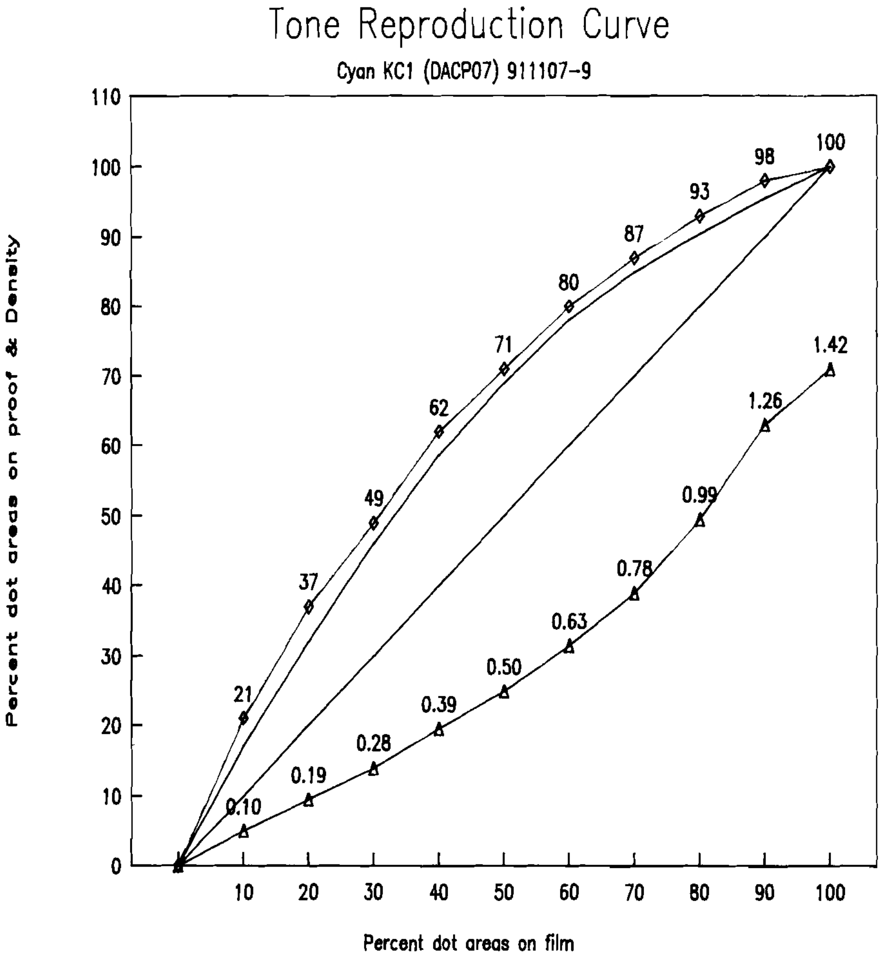
1983 Color: Essence and Logic. Van Nostrand Reinhold Co., New York, p. 116

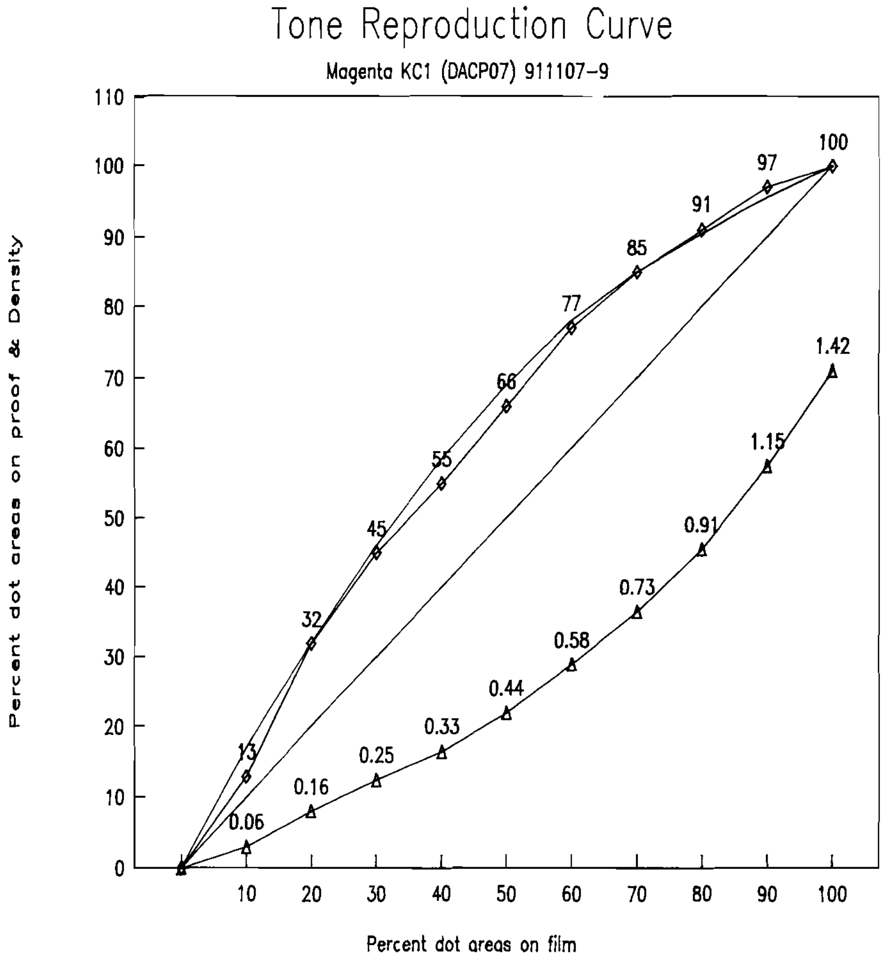
Southworth, M. & Southworth, Donna

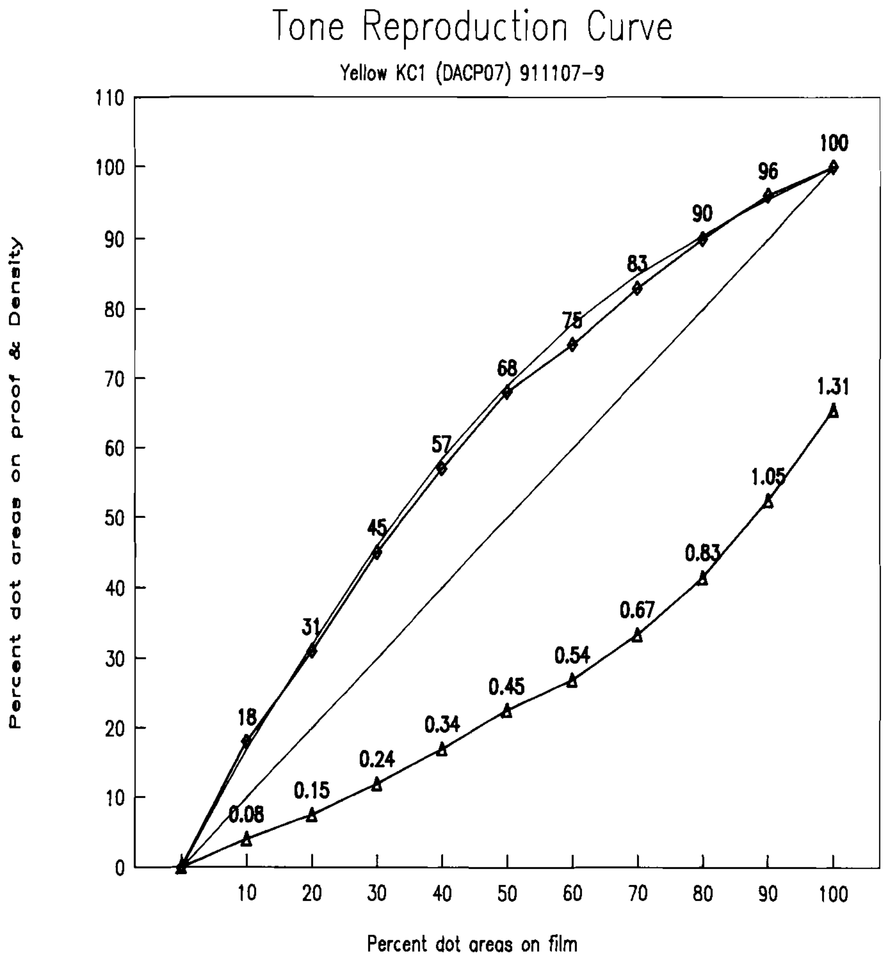
1989 Quality and Productivity in the Graphic Arts. Graphic Arts Publishing, Livonia, N.Y., pp. 15-21, 15-5

Appendixes

1. Four tone reproduction curves of the sample.

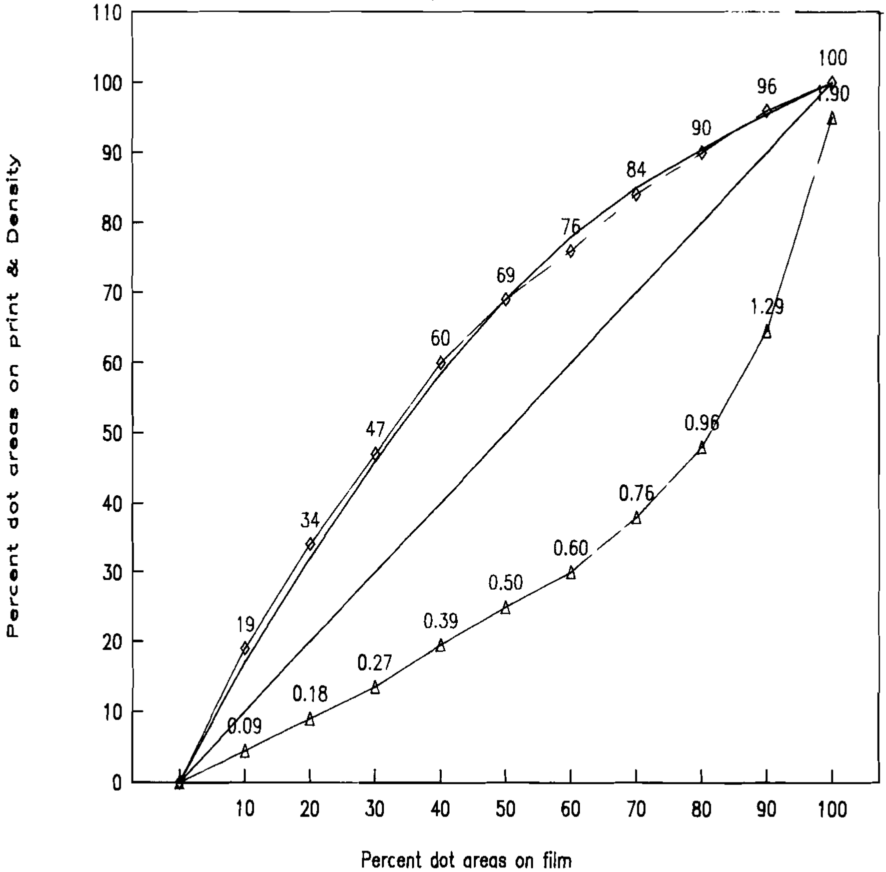



Tone Reproduction Curve
Magenta KC1 (DACP07) 911107-9
Percent dot areas on proof & Density
Percent dot areas on film
0
10
20
30
40
50
60
70
80
90
100
110
13
32
45
55
66
77
85
91
97
100
0.06
0.16
0.25
0.33
0.44
0.58
0.73
0.91
1.15
1.42


Tone Reproduction Curve
Yellow KC1 (DACP07) 911107-9
Percent dot areas on proof & Density
Percent dot areas on film
0
10
20
30
40
50
60
70
80
90
100
110
18
31
45
57
68
75
83
90
96
100
0.08
0.15
0.24
0.34
0.45
0.54
0.67
0.83
1.05
1.31

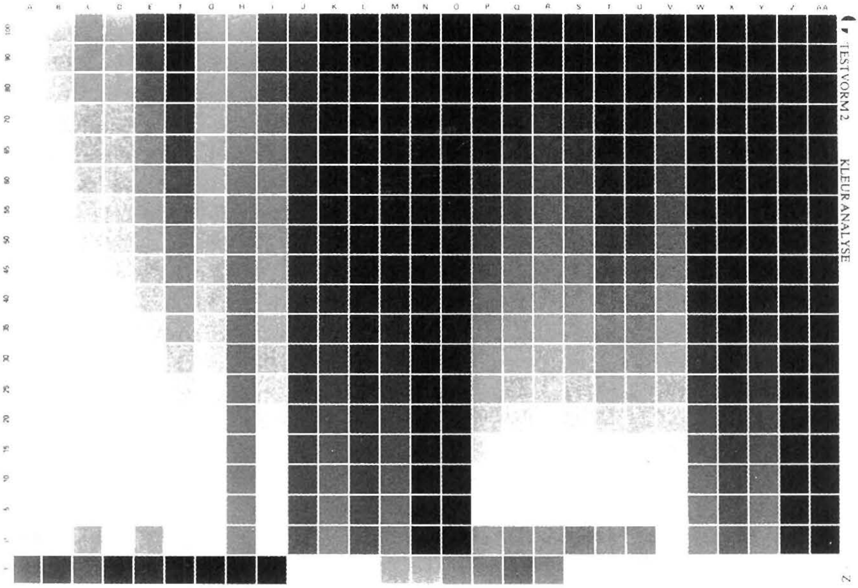
Tone Reproduction Curve

Black KC1 (DACP07) 911107-9



2. Illustrations

2.1. Test forms 1 and 2



2.2. Test forms 3 and 4