CONVERSION OF SOLID INK DENSITY AND DOT GAIN SPECIFICATIONS INTO COLORIMETRIC SPECIFICATIONS

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Abstract: Traditionally, printing standards and tolerances are defined in terms of solid density and dot gain. These standards have served the purpose quite well, as long as densitometers are used for quality control. The recent availability of reasonably priced, portable spectrophotometers and colorimeters gives the printing industry the option of using colorimetric methods for quality control. One possibility is to use a single 3-color gray patch for controlling a printing press. Now the question arises, what color tolerances should be used in terms of CIELAB?

Such tolerances can of course be obtained by simply observing a pressrun that is in statistical control. However, it would also be interesting to know how the existing dot gain and solid density tolerances would translate to colorimetric units. This paper describes such a conversion.

Because it would be impossible to accurately print all possible combinations of high and low values of solid density and dot gain tolerances for all colors, a mathematical model, utilizing n-modified, spectral Neugebauer equations, is used to do the conversion. The resulting cluster of grays has a near spherical, ellipsoidal shape when plotted in CIELAB space.

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* This paper is based on the master's thesis of Theera Tangvichachan at Rochester Institute of Technology. Both Franz Sigg and Stephen Viggiano were thesis advisors and teach at the School of Printing. Stephen Viggiano works at the RIT Research Corporation.

Introduction

Historically, printers were, and still are, using densitometers to obtain an objective evaluation of press performance. At first only solid ink densities (SID) were monitored. Later on tints were also measured in order to evaluate dot gain, using the Murray Davis equation. Today there are various international standards and recommendations that specify what solid densities and dot gain aim values and tolerances should be used. These standards differentiate between several classes of work (sheet fed, web, coated or uncoated paper) and several densitometric responses (wide band, narrow band, spectral filters, polarized or non polarized). This approach to specifying printing is successful to the degree that a printer or client could prove in court that a given job was printed properly or not. Even though densitometers do not respond to color like the human eye does, they are very well suited for *process control*, where we simply need to know whether a process remains stable within given limits.

Recently, portable spectrophotometers, specifically designed for applications in the graphic arts, have become available at a reasonable price. So far, these instruments were primarily used to colorimetrically monitor special, non process color applications, where densitometry would be inadequate. However, it is possible to use such instruments also for the control of process color. This requires more powerful software for analysis, but it may simplify the work of the press operator.[1]

One possible approach consists in measuring a single, dark, 3-color gray patch (and possibly a gray produced by a black halftone) for process control. The reason for this is the following: There is no dot gain adjustment knob on the press. Once production starts, the press operator can adjust the ink supply, and precious little else, to maintain the desired appearance of the printed image. Ink supply is directly related to solid ink density (SID). But even though SID is kept constant, dot gain may still vary. For instance, at the beginning of a press run, when the press is still cold, the amount of dot gain is low. After a number of impressions, the press starts warming up. When temperature increases, ink viscosity and ink tack will decrease. As a result, dot gain increases. In order to compensate for this darkening of the midtones of the image, all that the press operator can do is to reduce the amount of ink. However this also reduces the vividness of the saturated colors. Therefore there needs to be an adjustment that is a compromise between a midtone that is too dark and a solid that is too light.

A practical strategy to reach this compromise consists of keeping a 3/4 tone constant [2,3] (See Figure 1). In order to do this simultaneously for all three process colors, we can choose a dark neutral gray patch as a test target, and attempt to keep it neutral and of constant darkness. This method even compensates for possible variation in trapping. Additionally, in order to control the black printer, we may also print a black halftone patch besides the 3-color gray, and choose the dot area of the black such that the two patches have the same density. Such a design facilitates visual evaluation in addition to instrumental evaluation.

This method is simpler, because we now can get all the necessary information from the measurement of two patches, whereas the densitometric method needs measurements on 8 patches (4 solids and 4 tints).

If we were to use such a methodology, the question arises: What colorimetric aim values and tolerances should we use to control this 3-color gray patch?

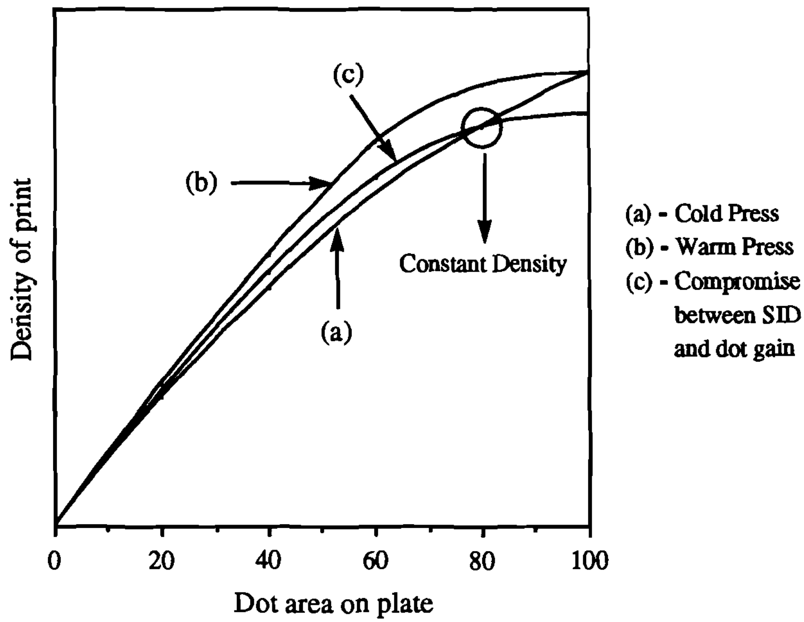


Figure 1. Use of 3/4 tone to control press.

One way to find out the minimum tolerances would be to print while the press is in statistical control, and observe the resulting variation. However, it would also be interesting to know how the existing densitometric dot gain and solid density tolerances would translate to colorimetric units. This paper describes such a conversion.

Methodology

Theoretically, one could make prints with all possible combinations of high and low tolerances for SID's and dot gains for all 3 process colors and measure the resulting near grays. However, nobody is able to control a press to such an extent that all these grays could be printed accurately. Therefore it was decided to use mathematical models to simulate the relationships. Spectral, n-modified Neugebauer Equations [4] were used for the conversion.

In order to apply those equations, one has to decide on specific printing conditions that should be modelled. High quality sheet fed printing on coated paper was chosen. The FIPP specifications were selected because they were the most comprehensive. They specify the following conditions for the European ink set and for narrow band, non polarized densitometry:

SID's: cyan 1.3, magenta 1.4, yellow 1.3. Tolerance ± 0.10.

Dot gain for a 50% dot and positive working plates for all colors: 19%. Tolerance ± 2%

In theory there would be $3^3 = 27$ combinations for the solids and also for the dot gains. But FIPP specifies that the tolerance values for both SID and dot gain should be either uniformly high or low. Therefore a combination that contains both a low and a high tolerance value is out of specification. This reduces the allowable combinations for both SID and dot gain to 15 each. Because there are 15 SID combinations and 15 dot gain combinations, there are a total of 15x15 = 225 possible combinations to form a gray.

It was decided to use the gray patch of the Gretag CMS3 color control bar as aim gray. It has dot areas of 75% cyan, 62% magenta and 60% yellow, which also correspond to recommendations by FOGRA. It is designed to have the same darkness as a black halftone patch of 80% dot area when printed according The FIPP Specifications.

A set of spectral reflectance values for the Neugebauer primaries for the European ink set was obtained from Ugra. These spectral curves were taken as aim values for the solid densities. From this set of data, the 15 low and high tolerance value combinations had to be calculated. An unpublished computer program, written by J. A. Stephen Viggiano, was used to perform this task.

NOTE: In order to generate the various dot area combinations, some conversion of the FIPP data was required. The FIPP data is based on the use of the Murray-Davies equation, but this does not yield mechanical dot area when the printing is done on paper. Rather than calling the result from the Murray-Davies equation "dot area" it should be more accurately described as "Effective Relative Absorptance," or ERA. The change in ERA from film to paper may then be called "Delta ERA." Most so-called dot gain specifications are, in fact, given in terms of Delta ERA.

It was necessary to translate the Delta ERA specifications given in FIPP into (mechanical) dot gain values. The relationship between Delta ERA and dot gain is complicated, and depends on Solid Ink Density, the Yule-Nielsen n-value, spectral characteristics, and a host of other factors. FIPP specifies Delta ERA values of 19 percent for 50 percent dots on film. This translates into an ERA value of 69 percent, or 0.69. Knowing the Solid Ink Densities, this ERA value may be converted into a tint density for each ink, using the Murray-Davies equation. See the table below.

Ink	Density of Solid	Density of Tint	Dot Area on Print	Dot Gain
Cyan	1.458	0.4762	0.5205	2.05%
Magenta	1.434	0.4744	0.5084	0.84%
Yellow	1.241	0.4564	0.5364	3.64%

For 150 lines per inch halftones on coated paper, an n-value of 2.0 has worked well. This value, together with the reflectance spectra of the solid inks and their overprints, were input to the model described in Reference 4. A search was conducted for the dot area of Cyan which would produce a Red-filter density of 0.4762. This was found to be 0.5205, slightly larger than a 52 percent dot. This corresponds to a true dot gain level of 2.05%. The procedure was repeated for Magenta and Yellow.

One may ask, "Why bother translating the Delta ERA specifications of FIPP into true dot gain values?" The reason is because Delta ERA specifications are incompatible with the accurate colorimetric model for halftone performance, and must be translated to mechanical dot area.

Finally, the CIELAB coordinates were calculated for each one of the 225 near gray combinations by using the spectral, n-modified Neugebauer equations. These 225 near grays were then graphically displayed and statistically analyzed by the JMP program.[5]

Results

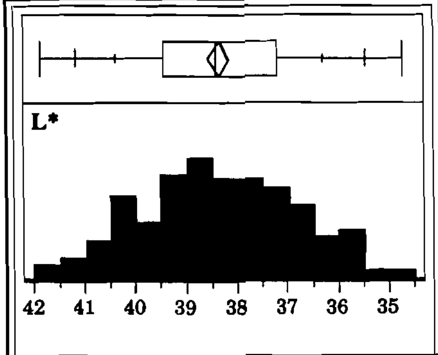
The densities that were calculated from the spectral data of the European ink set turned out to be different than the ones specified by FIPP. However, the FIPP densities were for SPI spectral products (20 nanometer bandwidth at half height) whereas the calculated densities were determined using Status E spectral responses which are wider in bandwidth. (Status E is similar to Status T, but the spectral products for the blue channel are based on the 47B filter instead the broader-band 47.)

The aim gray did not turn out to be exactly neutral. If it were exactly neutral, a^* and b^* would both have to be zero. The CIELAB coordinates of the aim gray were L^*=38.41, a^*=-1.08 and b^*=-7.89. This means that the aim gray has a slight bluish cast.

Such discrepancies are almost irrelevant to this study, because we are really only concerned with relative values. The basic interest is in the tolerances and not in the absolute values. Essentially, we would like to see the shape and distribution of the cluster of colors around the aim gray.

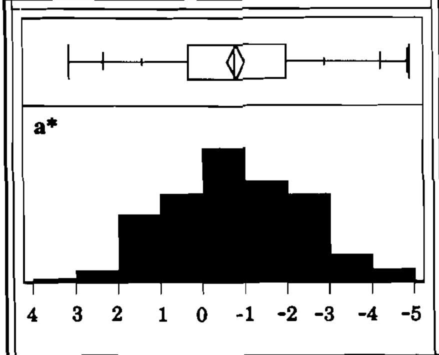
To visualize the distribution of the data, the JMP [5] program was used to create histograms and boxplots of each data set as illustrated in Figure 2. The histograms show that the data is normally distributed. The fact that the standard deviations for L^*, a^* and b^* are very similar indicates that none of the dimensions contribute more to color variation of the aim gray than any other one.

Figures 3 to 6 show the shape of the cluster of datapoints around the aim gray as plotted by JMP. The aim gray is represented by □ . The bold crosses represent data points that fall outside the 95% probability, but are still within the 99% probability. The origin of the graphs is the average of the L^*, a^* and b^* data.



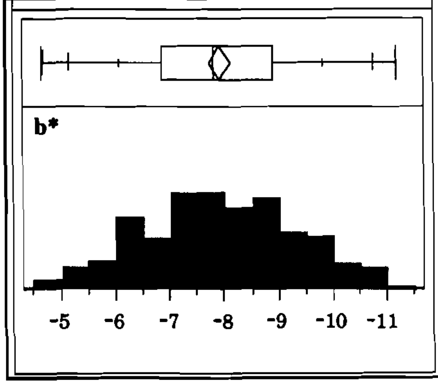
Statistical Analysis on L* by JMP

Max	41.8800
Min	34.7400
Median	38.4100
Mean	38.3508
Std Dev	1.5737
Std Err Mean	0.1049
Upper 95% Mean	38.5575
Lower 95% Mean	38.1440
N	225.0000
Sum Wgts	225.0000



Statistical Analysis on a* by JMP

Max	3.1700
Min	-4.8800
Median	-0.7600
Mean	-0.7830
Std Dev	1.6392
Std Err Mean	0.1093
Upper 95% Mean	-0.5676
Lower 95% Mean	-0.9983
N	225.0000
Sum Wgts	225.0000



Statistical Analysis on b* by JMP

Max	-4.6700
Min	-11.1800
Median	-7.8100
Mean	-7.9220
Std Dev	1.4158
Std Err Mean	0.0944
Upper 95% Mean	-7.7360
Lower 95% Mean	-8.1080
N	225.0000
Sum Wgts	225.0000

Figure 2. Histograms, boxplots and statistical analysis for L^*, a^* and b^*.

The largest ΔE^* value among the 225 grays was 4.74 units. This value confirms previous findings of acceptable tolerances for printing. Scott Stamm[6] found that a ΔE^* value of 6 was an appropriate tolerance for printing.

In order to determine the three axes of the ellipsoid, a Principal Component Analysis was performed by using the JMP program. The three eigenvalues, which are variances, have a value of 1.25, 0.96 and 0.79. In order to get numbers that are proportional to the length of the axes, the square root of these variances must be taken. Numbers that are proportional to the length of these axes are therefore 1.12, 0.98 and 0.89. If they were identical, the shape of the cluster would be spherical. The ratio

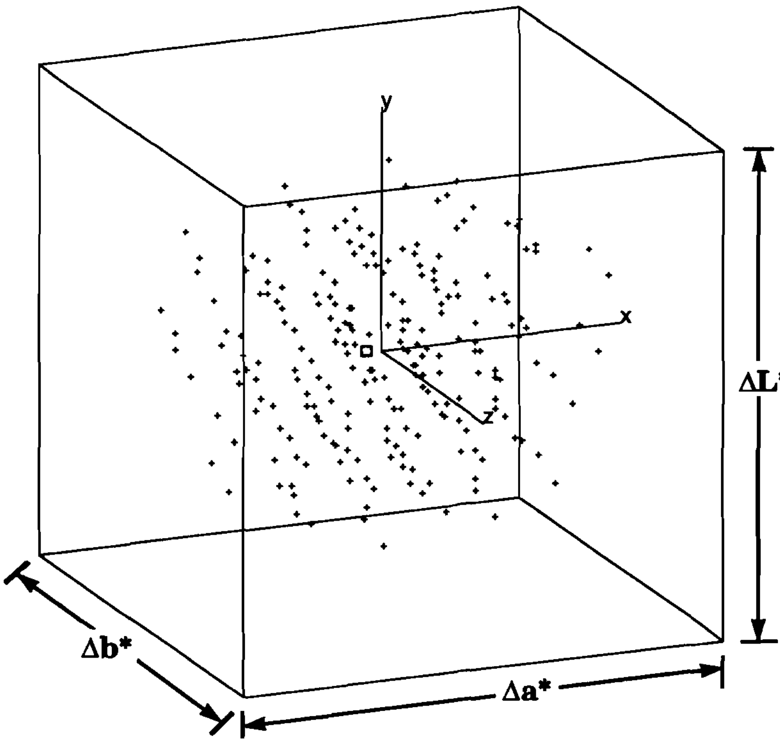


Figure 3. Three dimensional plot of the cluster of the 225 grays.

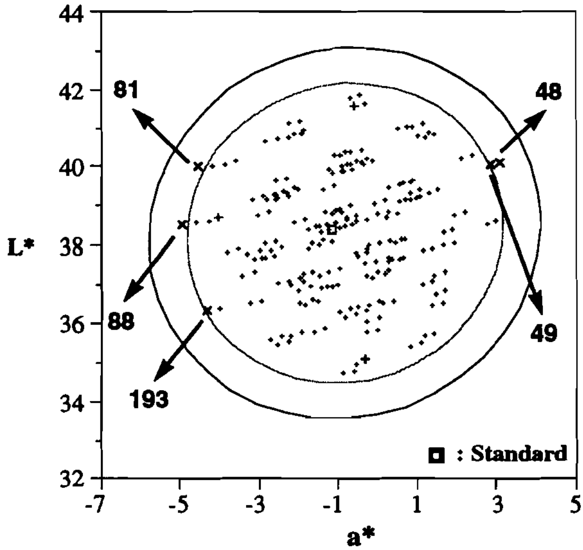


Figure 4. View of the cluster in the L^* a^* plane. The ellipses show 95% and 99% limits.

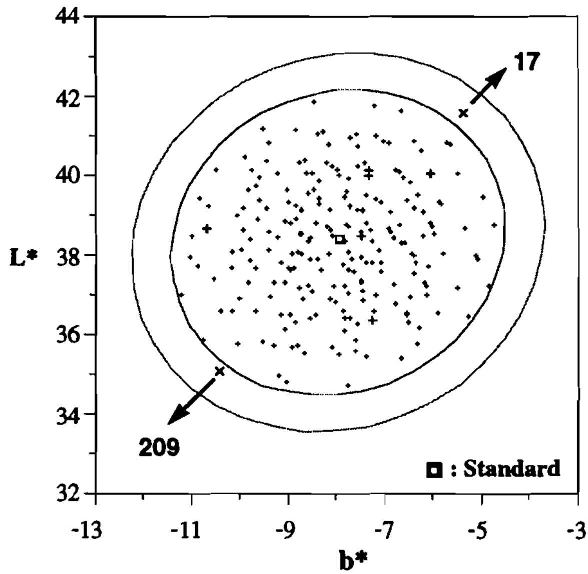


Figure 5. View of the cluster in the L^* b^* plane.

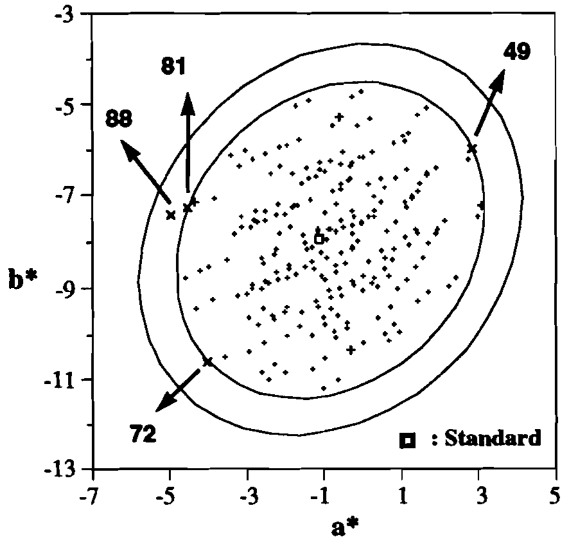


Figure 6. View of the cluster in the $a^* b^*$ plane.

between the length of the longest axis and the shortest axis is close to one (1.26). Therefore, the ellipsoid is almost a sphere.

In order to find out whether the 0.1 plus-minus variation of the solids was comparable in its effect to the 2% plus-minus variation of the dot gains, the average ΔE^* values for these two variables were calculated. The average ΔE^* value due to the variation of the solids is 2.06 and the average ΔE^* value due to the variation of the dot gains is 1.82.

Conclusions

A colorimetric tolerance of ±5 ΔE^* units on a dark gray is equivalent to a densitometric tolerance of ±0.10 solid density and ±2% dot gain in the mid tones for all 3 process inks. Either solid density variation of ±0.10 or dot gain variation of ±2% contribute about the same amount to variation. Changes of cyan cause a little more variation than changes of yellow. Magenta lies in between. But the differences are small.

References

1. One such system that has been in commercial use for several years is the Heidelberg CPC 2S automatic spectral press sheet scanner.

2. Dr. Friedrich Dolezalek, FOGRA Munich
   1988. "Wann Druckkontrolle nach Vollton, wann nach Raster?" (XIV. Woche der Druckindustrie, Fachveranstaltung Offsetdruck, 27. Okt. 88), 5 pp.

3. Besson, K-H., FOGRA
   1988. "Rasterdichte oder Volltondichte – Welche Vorgabe eignet sich besser für das Einrichten und den Fortdruck?," (Bundesverband Druck E.V.), Informationen II/1988, Art. Nr. 86422, 8 pp.

4. J. A. Stephen Viggiano
   1990. "Modeling the Color of Multi-Colored Halftones," TAGA 1990, pp 44-62.

5. JMP Ver. 2.0 (Cary, NC:SAS Institute). See also
   Robert Chung and John Compton
   1991. "A Colorimetric Method for Visualizing and Determining Color Tolerances of Printed Colors," TAGA pp 119-129

6. Scott Stamm
   1980. "A Colorimetric Investigation of Color Tolerances," M.S. thesis, School of Printing, Rochester Institute of Technology.
   1981. TAGA, pp 156-173.