

Further Analyses of the Relationship Between Midtone Spread and ΔC_h

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Abstract

Midtone spread (MTS) and chromaticness difference (ΔC_h) are synonymous, but differ in metric and test method. Midtone spread measures the departure of C, M, and Y midtone balance in terms of TVI. Chromaticness difference is the colorimetric difference between a printed CMY triplet and its colorimetric aim with approximately the same lightness. Either midtone spread or chromaticness difference can be used to specify tolerance, but do not yield the same outcome. As the printing standards community contemplating the conversion between midtone spread and chromaticness difference, this research is aimed at determining ΔC_h that is equivalent of 5 MTS using a real printing database as opposed to a previous study using a simulated database. Using ΔC_h to communicate visual difference in pictorial images and controlling ΔC_h or TVI during color printing, by varying solid ink density, are also studied.

Introduction

Printing process control standards, developed in the 1970s and 1980s, were primarily based on densitometry. If a printer used certified inks, controlled CMYK ink film thickness, and TVI of midtone by densitometry, printed color would conform to specifications.

When off-press color proofing system was developed, photographic dyes and inkjet inks were used that differed from printing inks. Calibrating a proofing process by densitometry would fail because density directly relates to light absorption and not color. This prompted the change in process control parameters from densitometry to colorimetry in the 1990s. Today,

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printing process control standards are primarily based on colorimetry. As such, solid ink density (SID) has been replaced by CIELAB value, Δ SID has been replaced by Δ E value, and densitometric TVI has been replaced by colorimetric TVI.

Literature Review

Midtone spread (MTS) is the combined differences between TVI measurements of CMY midtone tints and their aims. Chromaticness difference (Δ C_h) is the quantitative difference between two near neutrals of approximately the same lightness. ISO 12647-2 (ISO, 2013) specifies 5 MTS as a normative requirement and 3.8 Δ C_h as an informative requirement. But there is no literature explaining how the conversion is done. A research question arises, “What is the equivalency between midtone spread and chromaticness difference in a database?”

The %agreement method was used in the TAGA 2013 study with a simulated database of 256 printing jobs based on four actual printing conditions (Sheng and Chung, 2013). The simulation alters the midtone TVI of C, M, and Y in Photoshop. Thus, the midtone spread (MTS) represents the independent variable, and the chromaticness difference (Δ C_h) represents the dependent variable. The TAGA 2013 study concluded that the tolerance of 5 MTS for a midtone (50C40M40Y) triplet is equivalent to 3.2 Δ C_h with 88% agreement.

There is an inherent limitation in the TAGA 2013 study, i.e., simulated printing jobs only vary in TVI, but not in solid coloration. Thus, a motivation of this study is to determine Δ C_h that is equivalent to the tolerance of 5 midtone spread using a real printing database.

Methodology

Tolerance specifies the metric and the permissive difference between sample measurements and the aim. In color printing, the specification of the tolerance may be based on perceptibility or acceptability. Perceptibility-based tolerance is generally too stringent to be applicable in printing. Acceptability-based tolerance, recognizing that the outcome still fits its intended use, is the right approach.

If tolerance metric_2 is to replace tolerance metric_1, a logical approach is to determine the equivalency between the two metrics with a printing database that includes passed and failed jobs using the procedure described below:

1. For each tolerance metric, compute the difference between the samples and the aim. Plot the difference in metric_1 and the difference in metric_2, as shown in Figure 1. A, B, C, and D are jobs of tolerance metric_1 vs. tolerance metric_2 in the database.

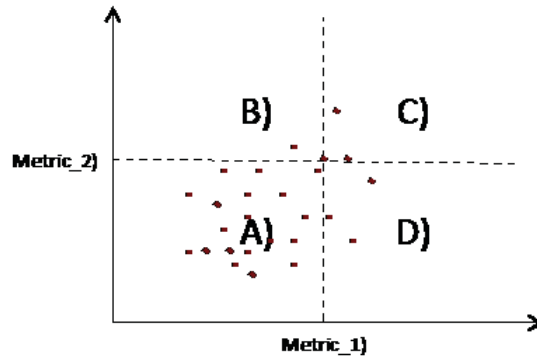


Figure 1. A generic description of two tolerance metrics in a database

2. Find the %pass as a function of tolerance of the two metrics, i.e., each metric only tracks jobs that pass, i.e.,

$$\%pass(\text{metric}_1) = (A+B)/(A+B+C+D) \quad \text{Eq. (1)}$$

$$\%pass(\text{metric}_2) = (A+D)/(A+B+C+D) \quad \text{Eq. (2)}$$

In general, %pass increases as the tolerance increases.

3. Find the metric_2 that would yield the same %pass at the specified tolerance of metric_1.
4. Find the %agreement between the metrics pair with equal %pass, i.e., both metrics pass or fail a given job or

$$\%agreement(\text{metric}_1 \text{ and } 2) = (A+C)/(A+B+C+D) \quad \text{Eq. (3)}$$

Berns' optimization method can also be used to find the %agreement (Wiley, 2000).

A key resource in this research is the real printing database of 637 jobs. There are 505 sheet-fed offset jobs, 46 web offset jobs, and 86 digital printing (laser and inkjet) jobs in the real database (Figure 2).

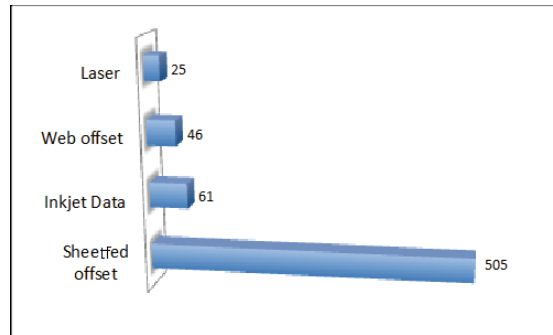


Figure 2. Real printing database by press type

All jobs included the P2P measurement files and were used to assess dataset conformity in an earlier study reported by Urbain and Chung (TAGA, 2013).

To answer the research question, “what is the tolerance equivalency between ΔC_h and 5 MTS from a real printing database,” the following procedures are used:

1. Use the CIELAB values of the paper, CMY triplets, and K tints to define colorimetric aims of a job according to CGATS TR015 (Annex C).
2. For each job, compute TVI, MTS, and ΔC_h between the colorimetric aims and the measurements.
3. Repeat step (1) and (2) until all jobs in the database are processed.
4. Find ΔC_h that yields equal %pass as 5 MTS and their %agreement.

We also want to explore the following related research questions, i.e., how to visualize ΔC_h and control ΔC_h during printing?

Results

For all three triplets, the equivalent ΔC_h to 5 MTS and their %agreement from the real database, as shown in Table 1, are lower than that from the simulated database. For example, the mid-tone ΔC_h tolerance of 1.76 and 5 MTS has a 58% agreement in the real database. This is in comparison to the mid-tone ΔC_h tolerance of 3.2 with an 88% agreement in the simulated database.

CMY Triplet	Real Database (n=637)		Simulated Database (n=256)	
	ΔC_h	% agreement	ΔC_h	% agreement
25C19M19Y	1.22	65	1.8	87
50C40M40Y	1.76	58	3.2	88
75C66M66Y	2.29	50	3.3	77

Table 1. Equivalency and %agreement between midtone spread and ΔC_h

A possible cause of the above difference relates to the fact that real printing jobs vary in TVI and in solid coloration, but simulated printing jobs only vary in TVI. The other possible cause of low %agreement is that digital printing jobs in the real database use color management, not on primaries and TVI, to achieve printing conformity.

Figure 3 illustrates the quantitative relationship between the midtone spread and ΔC_h at the 50C40M40Y triplet. As mentioned earlier, 86 jobs (14%) in the real database are from digital presses. Digital presses depend on color management, not primaries and TVIs, to achieve printing conformity. As such, many jobs with low ΔC_h (lower right quadrant of Figure 2) and high MTS are likely to cause low %agreement.

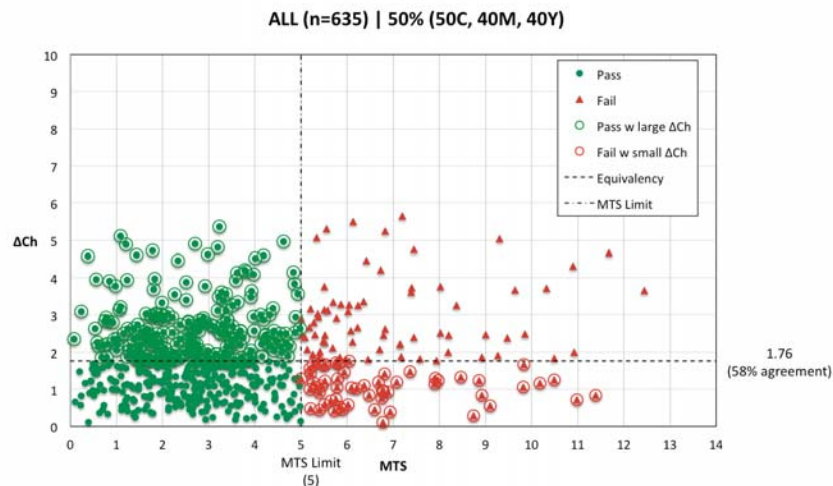


Figure 3. Midtone spread vs. ΔC_h based a real database

The low %agreement between 5 midtone spread and ΔC_h relates to the differences in test method and composition of the database. Since tolerance is a man-made decision, ΔC_h tolerance should be based on acceptability and %pass from, not %agreement, a real printing database.

Discussion – Visualizing and controlling ΔC_h

If we focus on the chromaticness difference (ΔC_h) alone, we can create a starburst pattern by plotting line between the aims and measurements in the a*b* diagram. Figure 4 represents 64 jobs from the simulated database. The tolerance circle is 3.2 ΔC_h . Conforming jobs (short stems) are in green and non-conforming jobs (long stems) are in red.

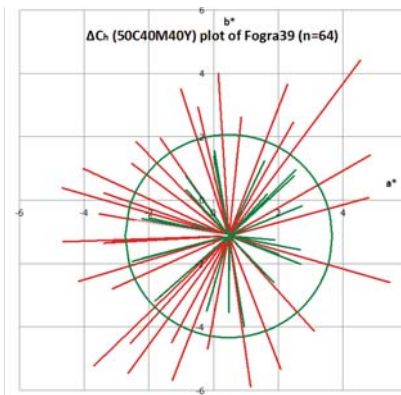


Figure 4. ΔC_h (50C40M40Y) plot of a simulated database

Figure 5 represents 254 jobs randomly selected from a total of 637 jobs in the real database. All measurements have their own colorimetric aims. In order to achieve the starburst effect, the plot uses the Δa^* and Δb^* relative to colorimetric aims. The midtone tolerance is set at $1.76 \Delta C_h$.

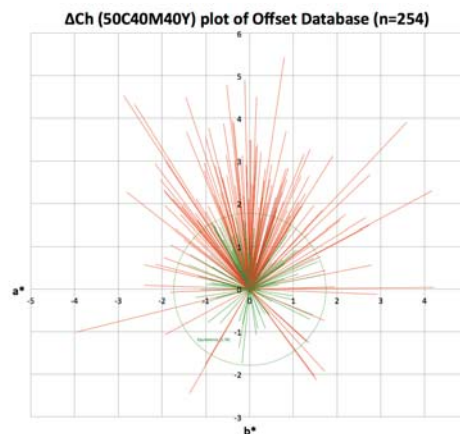


Figure 5. ΔC_h (50C40M40Y) plot of a subset of the real database

Relating the starburst effect to the visual space

The direction and magnitude of the starburst plot indicates the gray balance performance of a printing job. An interesting question follows, “How can we relate the starburst effect to the visual space?”

Felix Brunner pioneered the concept of Picture Contrast Profile (PCP) by varying the midtone TVIs in four classes of images (TAGA, 1987). A hexagonal-shaped image cluster was devised to indicate that visual difference depends on midtone spread as well as the color image contrast. In this research, we use ΔC_h , not ΔTVI , to communicate in visual space with the following procedures:

1. Use Adobe Photoshop to create a hexagonal-shaped gray patch with a CIELAB value (L^*_0, a^*_0, b^*_0).
2. Vary a^* and b^* of the gray patch so that six hexagonal-shaped gray patches have known hue angles and equal ΔC_h .
3. Assemble gray patches in the hexagonal layout (Figure 6).

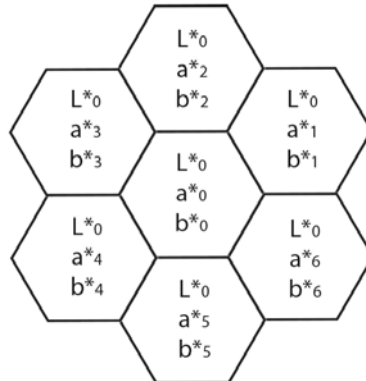


Figure 6. Hexagonal-shaped layout

4. Repeat the above steps 1-3 to present ΔC_h variations for different pictorial color images.

Figure 7 (left) shows the gray variation hexagon. The center is the reference. The inner ring has a chromaticness difference of $2\Delta C_h$. The outer ring has a chromaticness difference of $4\Delta C_h$. Figure 7 (right) shows how these patches differ in appearance with varying levels of ΔC_h in different hues.

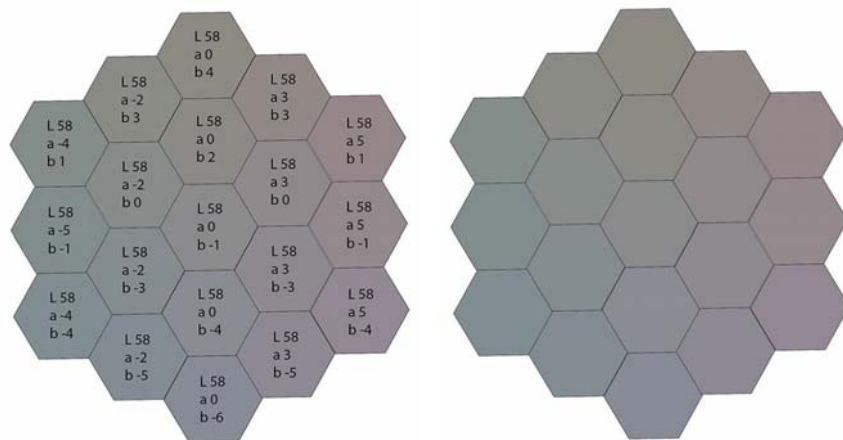


Figure 7. Gray balance variation with varying ΔC_h

Figure 8 illustrates the same ΔC_h variation, as used in Figure 6, using near-neutral pictorial color image. The image on the left side of Figure 7 is a $2\Delta C_h$ variation ring. The image on the right side of Figure 8 is a $4\Delta C_h$ variation ring. Notice that images with gray and dominant near-neutral contents show noticeable changes in appearance due to changes in ΔC_h .



Figure 8. Gray balance variation of a near-neutral image

Figure 9 illustrates the same ΔC_h variation, $2\Delta C_h$ and $4\Delta C_h$, using a high-chroma pictorial image. Notice that images with high-chroma contents do not show noticeable visual changes as the neutrals do. This means that monitoring and controlling ΔC_h of a CMY triplet may be an effective process control strategy in process color printing.



Figure 9. Gray balance variation of a high-chroma pictorial image

Controlling ΔC_h or TVI during printing

ΔC_h and TVIs are related. TVIs and CMYK solids are related. Since there is no direct control of TVI on a running offset press, we need to understand how TVI is affected by changes in solid ink density that the pressman can control. To investigate the relationship between TVI and SID in a press run, the following procedures were used:

1. Print the 'Ink Starvation' test form using an offset press with ink keys set evenly across the width of the press (Figure 10).

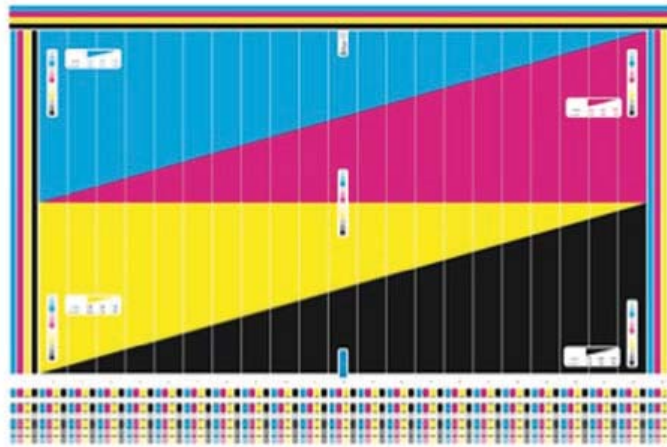


Figure 10. 'Ink Starvation' test form

Due to the design of the wedge-shaped ink pick-up zones across the width of the press sheet, high ink pick-up zones will yield low solid ink densities and vice versa. Thus, varying solid ink densities are obtained from a single press sheet with minimum amount of noise, e.g., intermittent dot slur and doubling.

2. Measure CIELAB and density values of solids, tints, including paper, across the width of the sheet.
3. Compute colorimetric TVI per ISO 13655 (2009).
4. Plot graphs of ΔTVI vs. ΔSID for each of the CMYK colors.

Figure 11 shows the relationship between TVI and solid ink density of C, M, Y, and K. In general, changes in TVI are proportional to changes in SID. The difference is that different inks operate in different density ranges and in different slopes.

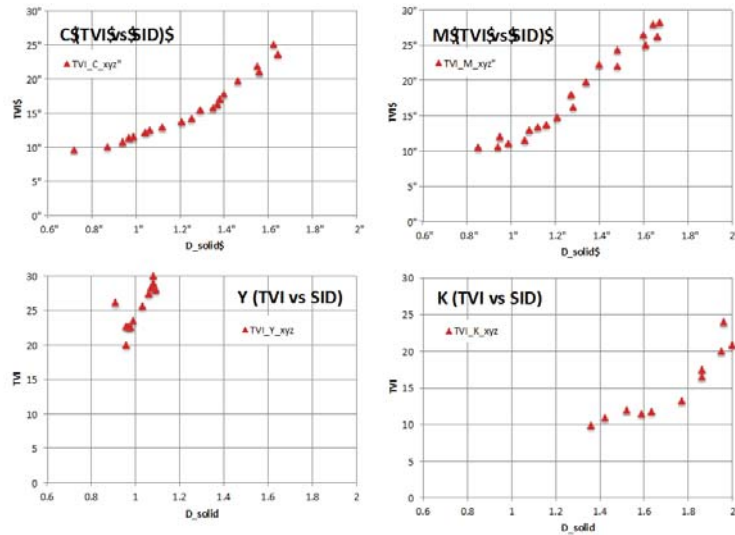


Figure 11. TVI change as a function of CMYK solid ink density change

Table 2 summarizes that it requires a change of 0.05-0.06 solid ink density to change 1% TVI in cyan, magenta, and black printer. But, it only requires a change in 0.02 yellow SID to cause a 1% TVI change in the yellow printer.

	C	M	Y	K
SID_max	1.64	1.70	1.12	2.03
SID_min	0.71	0.85	0.89	1.36
Range_SID	0.93	0.85	0.23	0.67
TVI_max	26.16	29.33	33.01	23.86
TVI_min	9.28	10.49	19.97	9.84
Range_TV	16.88	18.83	13.05	14.02
Ratio (D/TVI)	0.06	0.05	0.02	0.05

Table 2. Relationship between TVI and solid ink density

Based on the above findings, we concur with the findings reported by Raymond Prince, et al in that it is more effective to control solid ink density in color printing than controlling gray balance (TAGA, 2008). For printing process control, we recommend (1) calibrating the ink-paper-press condition and print to specified solid ink density, (2) adjusting TVI and ΔC_h in prepress, and (3) improving ΔC_h consistency by varying SID with extreme care.

Conclusions

We used a real database of over 600 offset and digital printing jobs and the prescribed methodology to determine the equivalency between midtone spread (MTS) and chromaticness difference (ΔC_h). The results show there is no strong agreement between 5 MST and ΔC_h that yield the same %agreement. Since tolerance is a man-made decision, the next step is to consider changes in ΔC_h tolerance as a function of %pass and acceptability level.

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