

Color Repeatability of Spot Color Printing

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Abstract

A methodology that quantifies variation as well as deviation of spot color printing is developed. Two types of color variations, i.e., spatial (side-to-side) and temporal (begin-to-end), are described. The use of the cumulative relative frequency (CRF) of ΔE , from colorimetric data collected across the width of the signature, was used to describe spatial variation or uniformity of spot color printing. When colorimetric data are measured from the same printing location over time, we can use the same CRF method to depict the temporal variation or consistency of a press run. The deviation of spot color is determined by the color difference between the average colorimetric values of the temporal samples and its aim point. To demonstrate the methodology, spatial uniformity between a gravure press and a sheet-fed offset press of the same job was compared. If the spatial variation is large and its magnitude is systematic, visual discontinuity of overlapped edges becomes noticeable. The phenomenon is termed, spatial creeping. $\Delta E(ab)$ and $\Delta E(00)$ formulas are compared for their abilities to predict visual color differences. This methodology provides us a means for quantifying spot color repeatability of any printing process.

Introduction

Consistency and accuracy of spot color in packaging graphics are prerequisites to quality merchandising, branding, and customer loyalty. Today, color variations have been evidenced anecdotally and often resulted in customer intervention, pressroom wastes, product downgrading, etc. Although there has been discussion of the need to quantify spot color variation, there is no standardized methods and practices in doing so.

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ISO 12647-1 (1996) defines variation and deviation as two aspects of color repeatability. Variation, or precision, is a measure of similarities or differences among samples taken at random from the production. We further divide variation into spatial (side to side) uniformity and temporal (begin-to-end) consistency. Deviation or accuracy is the difference between the average of a production run and the aim point.

Both spot color and process colors are used in packaging printing. Spot colors apply to company logos and product brands. It requires the use of a dedicated printing unit with specially formulated ink. Process color applies to printing color images using a limited number of process inks. Spot colors may be produced using process inks. The nature of the variation in spot color printing is less complicated than in process color printing. For example, the colorimetric difference due to ink film thickness change of single ink is primarily in chroma; the ink film thicknesses change of process inks can result color changes in lightness, hue and chroma. The scope of this research is limited to color variations of the spot color printing only.

Review of Literature

Most researches on the variability of printing have been around the temporal (begin-to-end) dimension. For examples, Friedrich Dolezalek (1994) appraised production run fluctuations of sheet-fed and web offset presses; Schlapfer and Widmer (1995) investigated color variations in gravure and web offset printing. These papers all focused on temporal variation of process color printing. No attention was given to spatial (side-to-side) variation of the printing process.

Methodology

There are three aspects of color repeatability in spot color printing, i.e., spatial uniformity, temporal consistency, and color deviation from aim. This paper describes how to assess the three aspects of color repeatability in spot color printing. To keep the data analysis manageable, it is important that spatial uniformity of a spot color is assessed first, temporal consistency be assess second, and color deviation of the press run last.

An example of printing a dark or navy blue spot color by a one-meter (40") wide gravure press will be used to illustrate each of the above scenarios. Additional examples will be cited to explore spatial variation between gravure and offset litho printed sheet of the same job, etc.

Assessing Spatial Uniformity

Spatial uniformity of a spot color is defined as the degree of inking uniformity within a single impression of a printing unit. Operationally,

spatial uniformity of a spot color is estimated by colorimetric measurements (D50, 2 degree) collected from across a printed sheet (Figure 1). No special test target is necessary for collecting color measurement data if the spot color is printed everywhere.

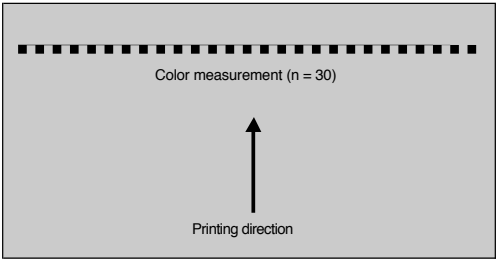


Figure 1. Color measurements from across the printing direction

Measurements collected can be across the printing direction (widthwise) and in the printing direction (lengthwise). Our experiences indicate that width (side-to-side) variation is more significant than circumferential (front-to-back) variation. To keep the process simple and effective, this methodology assesses spatial variation of spot color by measuring a total of 30 CIELAB values across the press sheet.

Spatial uniformity may be estimated by (a) the average ΔE , i.e., the sum of all ΔE s between the individual CIELAB values and the average CIELAB values divided by the number of measurements; and (b) the frequency distribution or its cumulative relative distribution of all ΔE s. Figure 2 is an example of the spatial uniformity expressed as a frequency histogram. It represents the variability of 30 color measurements. The histogram shows the pattern of variation. The average ΔE indicates the central tendency of all ΔE s.

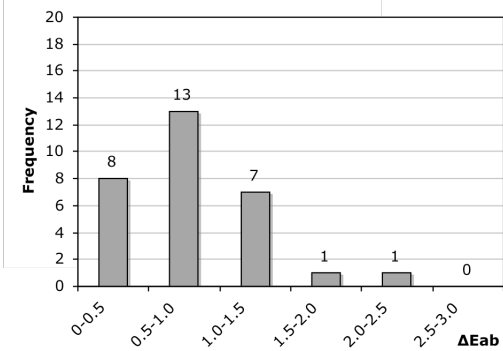


Figure 2. Spatial uniformity expressed as a histogram

It is the asymmetrical nature of the ΔE distribution, shown in Figure 2, limits the usefulness of the average and standard deviation. This

prompts the use of its cumulative relative frequency (CRF) to convey variability by mean of a graph (Chung, 2001). As shown in Figure 3, 50% of the ΔE s are 0.66 or less; 90% of the ΔE s are 1.27 or less; and the maximum ΔE is 2.19.

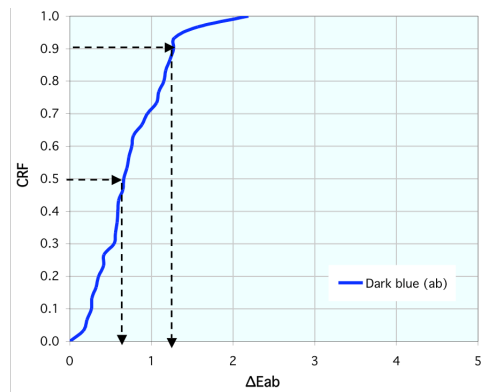


Figure 3. Spatial uniformity expressed as a CRF curve

The steeper the CRF curve is, the more uniform is the inking. When more than one sample is analyzed for spatial uniformity, they provide replications, thus, added confidence, regarding spatial uniformity associated with the printing process. In a calibrated press condition, colorimetric differences among these replicates are expected to be small, and the median of the average ΔE s can be used to represent the spatial uniformity of the printing unit. Figure 4 shows the CRF curves of three samples.

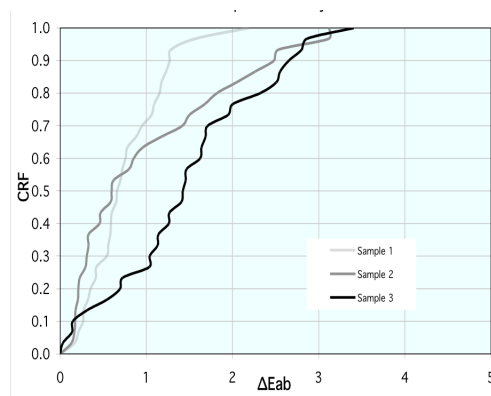


Figure 4. Spatial uniformity assessment from multiple samples

Assessing Temporal Consistency

Temporal consistency is a measure of inking repeatability over time. It measures time-dependent variation at a fixed location on the printed sheet (Figure 5). Operationally, the measurement location should be representative of the spot color in question, and is free from flaws. Measuring the spot color from a fixed location, therefore, assumes that the spatial uniformity, as detailed in the previous section, is known to be small, i. e., ΔE at 90% tile is less than 1.0.

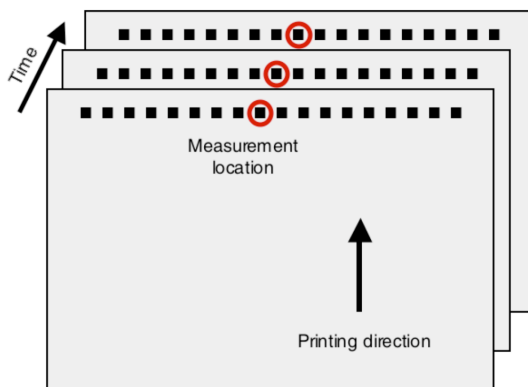


Figure 5. Schematic of sampling press sheet over time

A total of up to 30 samples are desired for temporal consistency analysis. These samples may be collected from a single reel to reflect the short-term variation or from many reels to reflect the long-term variation of the process. Temporal consistency is estimated by the cumulative distribution function (CRF) of all ΔE s between individual ΔE s and its average. Figure 6 illustrates the temporal variation of the navy blue spot color as a CRF curve.

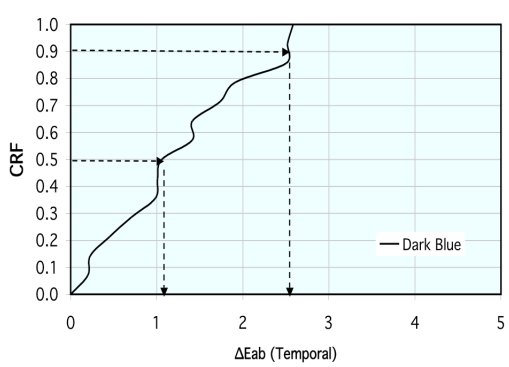


Figure 6. The CRF curves of temporal variation of a spot color

Summarizing Color Variations

Spatial uniformity and temporal consistency are two independent variables. Spatial uniformity depicts the mechanical calibration of the press. Temporal consistency illustrates the time-dependent variation, thus, the process stability. The color variation of spot color printing can be summarized in Table 1.

Table 1. Summary of special uniformity and temporal consistency

$\Delta E(ab)$	50 percentile	90 percentile	Max.
Spatial variation	0.66	1.27	2.19
Temporal variation	1.06	2.52	2.59

Assessing Color Deviation

A capable printing process is defined as a process that conforms to specifications. It implies that there are (1) aim points and tolerances, (2) estimates of the process average, and (3) documented evidence of conformance. In other words, a capable printing process not only demands precision, but also accuracy.

The deviation of a spot color indicates the accuracy of the printing process, and is determined by the ΔE between the target CIELAB values and the average CIELAB values of multiple press sheets over time. For example, Table 2 summarizes the result of deviation in terms of two ΔE metrics.

Table 2. Color deviation of the navy blue spot color

n =14	L*	a*	b*
Temporal Ave.	28.5	16.3	-67.2
Aim point	29.5	20.8	-71.5
Dev $\Delta E(ab)$	6.3		

By comparing the magnitude of color variation (Table 1) and color deviation (Table 2), one can quickly recognize that the batch-to-batch ink consistency has a greater impact on color repeatability of spot color printing than color variation within a sheet and sheet-to-sheet.

Discussion

Below are case studies that focus on color repeatability of spot color printing: (1) exploring spot color uniformity between a gravure and an offset printed job, (2) more on color variation and deviation; and (3) comparing color difference formulas, $\Delta E(ab)$ and $\Delta E(00)$.

Spatial Uniformity Between Gravure and Offset Litho

A 32" wide 4-color plus spot colors packaging job of Kitchen Bags was printed by offset litho and gravure. Press sheets from each of the printing processes were secured, courtesy of Packaging Corporation of America, and spatial uniformity of the lilac purple spot color was analyzed.

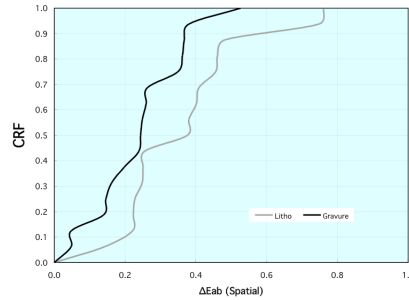


Figure 7. Spatial uniformity between gravure and offset litho

Figure 7 shows that spatial variations of both processes are small, i.e., the maximum ΔE is less than one ΔE , but the spatial variation of the gravure is undoubtedly smaller than offset litho. The single ink zone, the wiping of the doctor blade and the direct printing all contribute to spatial uniformity of gravure printing.

More on Spatial Variation

If the spatial variation is small in magnitude and random over the width of the press sheet, this is an indication of good mechanical conditions of the press. If the spatial variation is large in magnitude and random over distance, the press has too much slippage and is in need of an overhaul. If the spatial variation is large and its magnitude is systematic over distance, the press is out of balance and in need of a recalibration.

In packaging printing, substrates are printed flat. Opposite edges of the press sheet join when forming a box. Visual discontinuity of overlapped edges becomes noticeable when spatial variation is systematic. The phenomenon is termed, *spatial creeping*, by this author and can be demonstrated. Figure 8 shows a pattern with two rows connected in the center section. Row 1 and Row 2 appear to be identical in lightness.



Figure 8. Row 1 and Row 2 appear to be spatially uniform

Figure 9 shows the same pattern, but rearranged with the two opposing edges butting against each other in the middle. While Row 1 stays as a match, but Row 2 looks very different. The fact that we are unable to discern the systematic variation, as shown in Figure 8, is due to gradual shifts in lightness at either side of the pattern, hence, spatial creeping.

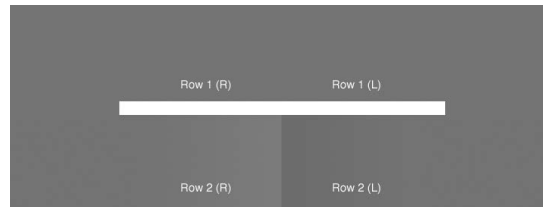


Figure 9. The same press sheet with noticeable difference

Incidentally, Figure 9 is an abstract version of the famous drawing of M. C. Escher (1961), *Waterfall*, in that the grays are connected (like water flows) until the point of visual discontinuity (waterfall).

More on Temporal Variation

If the magnitude of temporal variation is as small as the magnitude of spatial variation, then we have a very stable process. On the other hand, if the magnitude is much larger than the spatial variation, we need to know what to do to correct for the process drifts.

Temporal variation of spot color is primarily the ink film thickness that varies within a production run. Plotting C^* of the spot color over time is a good diagnostic step (Figure 10) for process control.

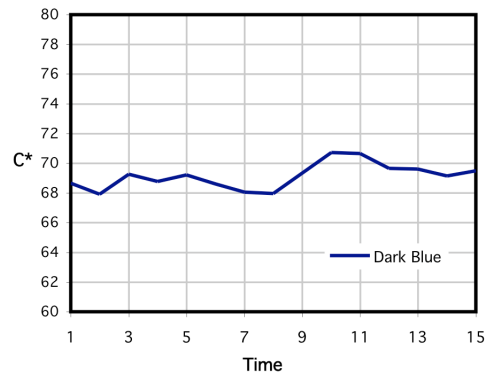


Figure 10. Control chart for monitoring C^* of the spot color

We also need to collect process variables, e.g., ink pan circulation, ink replenishment rate, ink viscosity, and make sure they stay in control. In other words, when key variables are stable and in control, temporal consistency is assured.

More on Color Deviation

Deviation of a spot color can also be summarized by ΔE between the target value and the sample average. The magnitude of deviation is mainly influenced by ink formulation and its dilution in the pressroom. Figure 11 is an example of a time plot with ΔE between individual CIELAB values and the target CIELAB value. In this instance, the deviation, $6.3 \Delta E(ab)$, is far greater than the tolerance of $2 \Delta E(ab)$.

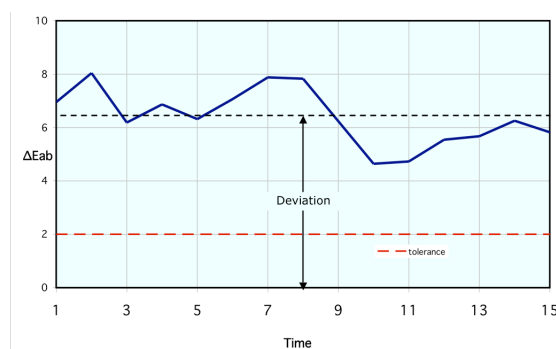


Figure 11. ΔE vs. time showing temporal variation and deviation

Comparing $\Delta E(ab)$ and $\Delta E(00)$

There are a number of CIE-based color difference formulas that are used to predict visual color differences between two colors. The color difference formula, $\Delta E(ab)$ has been used widely in the graphic arts industry. The color difference formula, $\Delta E(00)$, is the latest work of CIE that is yet to be adopted for industrial uses. Part of the difficulties in making the transition from $\Delta E(ab)$ to $\Delta E(00)$ is (1) there are abundant databases on $\Delta E(ab)$; (2) the availability of instrumentation, and (3) the computational procedures involved. The procedure for calculating $\Delta E(ab)$ is straightforward; the procedure for calculating $\Delta E(00)$ requires many formulas (Luo, et al., 2001). We used the Visual Basic code, provided by RIT Munsell Color Science Laboratory (2005), as a macro within Excel for $\Delta E(00)$ computation.

To find out how well $\Delta E(ab)$ and $\Delta E(00)$ formulas predict visual color differences, we prepared color sample pairs of varying hues, all with a color difference of $6 \Delta E(ab)$ between them. The equivalent color differences in $\Delta E(00)$ are smaller with the exception of the neutral pair (Table 3). Using the visual color difference between the gray pair as a reference, $\Delta E(00)$ predicts a smaller visual color difference between all other color sample pairs. By means of informal testing using college

students as observers, it became evident that $\Delta E(00)$ provides better prediction of perceived color difference than $\Delta E(ab)$ can.

Table 3. Color sample pairs with equal color difference in $\Delta E(ab)$

Color Pair		Left	Right	Δ	(Right-Left)	
					$\Delta E(ab)$	$\Delta E(00)$
Gray	L*	47.0	53.0	6.0	6.00	6.00
	a*	0.0	0.0	0.0		
	b*	0.0	0.0	0.0		
Red	L*	50.0	50.0	0.0	6.00	3.22
	a*	50.0	50.0	0.0		
	b*	22.0	28.0	6.0		
Green	L*	50.0	50.0	0.0	6.00	1.85
	a*	-53.0	-47.0	6.0		
	b*	0.0	0.0	0.0		
Yellow	L*	80.0	80.0	0.0	6.00	1.19
	a*	0.0	0.0	0.0		
	b*	87.0	93.0	6.0		
Blue	L*	50.0	50.0	0.0	6.00	3.05
	a*	10.0	10.0	0.0		
	b*	-43.0	-37.0	6.0		

To elaborate, both formulas predict color difference in neutrals the same. As the color pairs become chromatic, $\Delta E(00)$ predicts less perceived color difference than $\Delta E(ab)$ will. Consequently, the spatial CRF curve of $\Delta E(ab)$, shown in Figure 3, has a steeper slope in the $\Delta E(00)$ dimension (Figure 12). In addition, when spatial uniformity of spot colors with different hues are analyzed, their relative CRF locations are also affected in the $\Delta E(00)$ dimension (Figures 13 and 14). Specifically, yellow and green colors will have larger amount of shifts than red and blue colors.

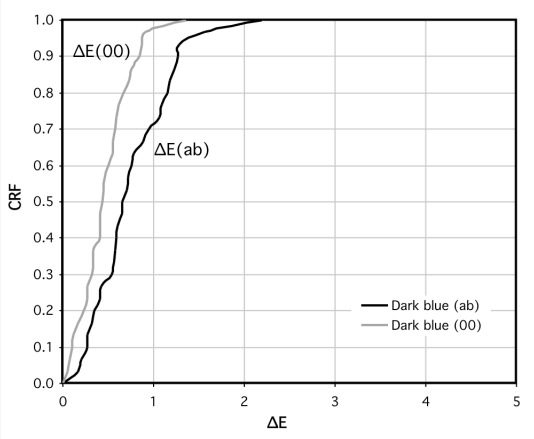


Figure 12. Spatial CRF curves of navy blue color in two ΔE dimensions

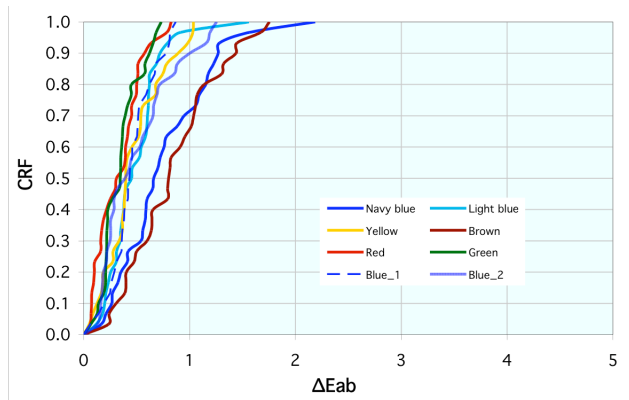


Figure 13. Spatial CRF curves of many spot colors in $\Delta E(ab)$ dimension

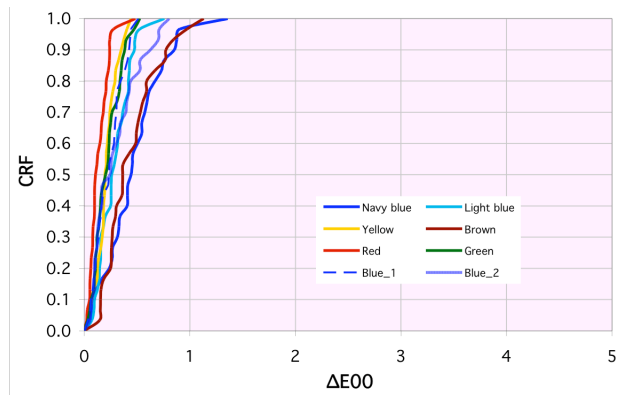


Figure 14. Spatial CRF curves of many spot colors in $\Delta E(00)$ dimension

Conclusions

Three aspects of spot color repeatability have been developed. Spatial uniformity and temporal consistency are expressed in terms of ΔE distributions (CRF). Spatial variation within a printed sheet is a function of press mechanical precision. Temporal variation within a press run reflects process drifts. Color deviation from aim is mainly affected by the consistency of ink supplied and formulated. In addition, the phenomenon of spatial creeping was demonstrated as a special cause of spatial variation that is visually significant. Finally, the $\Delta E(00)$ color difference formula predicts visual color differences of high chroma colors better than the $\Delta E(ab)$ color difference formula. The methodology provides a metric and a sound approach to assessing color repeatability of spot color printing of any printing process.

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