A COLORIMETRIC METHOD FOR VISUALIZING AND DETERMINING COLOR TOLERANCES OF PRINTED COLORS

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Abstract: For any color printing process, an ink or set of inks must be selected and standardized so that they always give the same result when printed in the same way. To approach this goal, both the visual method and instrumental method are used by printers to communicate color specifications and tolerances to their customers. Such color measurement methods are also used to monitor and control the printing process within its capability limits. This paper examines typical mechanisms of how colors and their tolerances are established by printers and some of the pitfalls these approaches have caused. Taking the above as a problem, a colorimetric method along with color tolerance modeling is explored as a solution in specifying not only the target or okay color, but also high/low or boundary colors based on a pre-established color tolerance limit. Since a color and its acceptable tolerance are described in a space, the volume as well as the shape of the tolerance sphere will be discussed in relationship to the number of over-printing conditions and the customer's expectation. A computer software with 3-D, spinning, and color-display capabilities is critical in visualizing and determining color tolerances for both communication and control of printed colors.

Process Capability vs. Product Specifications

Quality may be defined as meeting customers' requirements. This requires that customers alone, or with the help of print suppliers, provide realistic product specifications. It is preferred that specifications be quantitative, specifying quality characteristics of the product with aim points and tolerances. The other half of the quality equation is to ensure that products conform to specifications. This requires that printers understand their process capability and apply SPC to achieve accuracy and consistency in the print production process.

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The purpose of process capability studies is to help discover the inherent variation of the process. It does not ensure the full conformance of specifications. Indeed, one can have a printing process which is in statistical control but is not capable of meeting product specifications. The best outcome is that the process variation is less than product tolerances.

There are two objectives in this study: (1) to explore how color variation of printers' inks and their printing processes and products can be determined and visualized; and (2) to provide an effective approach to visual judgment and better color communication in determining color tolerances among print buyers, printers, and ink suppliers.

Measuring Color Variations

Color is a visual sensation. Trying to define color quality of printed product is not a trivial task. Print buyers often have difficulties in specifying tolerances of special colors such as those used in trademarks. The task becomes harder when specifying color tolerances for process image reproduction.

Printers are faced with equal challenges in determining color tolerances of incoming inks and process capability in relation to the color variation of the printing process. In either case, a method is needed which best describes color quality and its acceptability of the material or the process. Specifically, we need to decide (1) what metric to use, (2) where to measure, and (3) how to analyze the data and display the findings. The following offers further comments and the approach taken in this research.

Color measurement metrics, used in the graphic arts, can be classified into the following three categories: psychological, psychophysical, and physical. Human vision falls in the category of a psychological metric which offers the primary characteristics about color. But color tolerances determined by human vision with words is implicit in nature. Densitometry is an example of a physical metric of color assessment. It is easy to use, but has the inherent limitation of being an anomalous trichromat. CIE colorimetry, being a psychophysical response, offers the compromise. In this study, color measurement will be recorded in CIELAB units.

Another key element in determining color tolerance is the issue of where to measure. To find out the variation of incoming inks, sample swatches must be prepared in a standard fashion prior to color measurement. To assess color variation of process image reproduction, test targets or image spots on the press sheet may be sampled and measured. Here, we may measure solid areas of primary and secondary colors to observe changes in color gamut. We may measure 3-color overprint tints from a test target or an image to examine its gray stability over time. To assess color variation of special color printing, image spots on press sheet may be measured. In this paper, ink swatches of a process ink set were measured. Three-color overprint tints from a test target and an image spot from printed labels were also measured. These measurements will be discussed as case studies after the methodology is first explained.

When choosing data analysis and display tools, there are two criteria which must be fulfilled: (1) It must help quantify color variation according to the metric chosen, and (2) It must help visualize color variation. The first criterion is easy to satisfy with just about any spreadsheet software. But the second criterion is much harder to comply with effectively. The reason is that color has three attributes, i.e., color tolerances occupy a space, not just a plane. Previous studies[1,2] in setting color tolerances and displaying them either as a plane with the third attribute omitted, or as multiple slices (planes) of the tolerance space, are difficult to visualize. This study used computer software which is capable of displaying color tolerance data in three dimensions. More will be discussed on this topic later.

When determining color tolerances for process inks, the following factors play important roles: perceptibility, process capability, and historical patterns. Perceptibility means that the eye has the ability to discern small color differences, but this should not be the only criterion. By keeping the process capability and historical patterns of material acceptance in mind, these factors help define color tolerances more realistically.

Determining and Displaying Color Variations
using Excel and JMP Software

Excel is a spreadsheet software by Microsoft. JMP is a statistical analysis software by SAS. Both software run on a Macintosh computer and both have spreadsheet and graphing capabilities. However, JMP has a unique feature of displaying data in either one, two, or three dimensions. JMP also provides appropriate statistics for the first two display modes. The following offers examples of a one-dimensional and a two-dimensional display in JMP.

Color variation of a collection of yellow process inks is displayed in one dimension as shown in Figure 1. It shows color variation in three separate histograms. These histograms suggest that the three metrics (ΔL^*, Δa^*, Δb^*) are independent from one another. In reality, they are related to one another.

Figure 2 shows the same set of yellow ink data displayed in two dimensions with Δa^* and Δb^* plotted against each other. Due to the display being two-dimensional, information from the third dimension, or ΔL^*, is omitted. However, JMP offers a graphic analysis, called density ellipse at various probability levels. In comparison, Figure 2 is more meaningful in describing the nature of color variation than Figure 1.

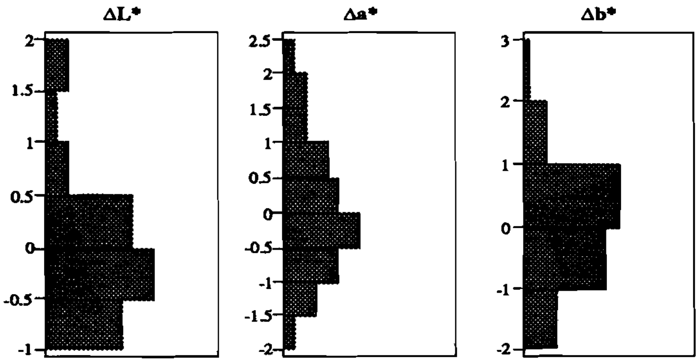

Figure 1. Color variation of a yellow process ink displayed in one dimension and modeled by histograms in JMP.

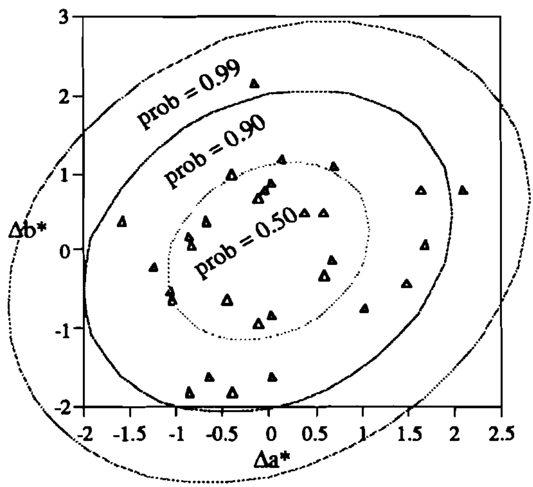

Figure 2. Color variation of a yellow process ink displayed in two dimensions and modeled by density ellipses in JMP.

Modeling Color Variation in Three Dimensions Using Excel and JMP

As mentioned before, JMP can display data in three dimensions which is most suitable for the analysis of color variation. But JMP does not provide statistics which describe or model the nature of color variation as ellipsoids. Thus, the following procedures describe how Excel and JMP are used to construct an ellipsoid which fits color variation data in three dimension.

A. Compute colorimetric differences from its average

1. Enter or import colorimetric data, i.e., L*, a*, b*, in the Excel spreadsheet.
2. Compute averages and standard deviations for L*, a*, and b*.
3. Compute colorimetric differences (ΔL^*, Δa^*, and Δb^*) by subtracting individual data from the average.

B. Establish parameters which model an ellipsoid in Excel

1. Use multiple standard deviations (abbreviated as 's') of ΔL^*, Δa^*, Δb^* as semi-axes of an ellipsoid, e.g., $\pm 3s_{L^*}$, $\pm 3s_{a^*}$, $\pm 3s_{b^*}$.
2. Choose an increment on ΔL^* dimension for a total of 30 points from $-3s_{L^*}$ to $+3s_{L^*}$. In this study, one-fifteenth of the ΔL^* semi-axis was used as the increment.
3. Compute locus for the $\Delta L^* \Delta a^*$ plane and the $\Delta L^* \Delta b^*$ plane. Figure 3 shows how the ΔL^* Δa^* plane is computed for every value in ΔL^* using the formula below:

$$\Delta a^* = \pm 3s_{a^*}\sqrt{1-\frac{\Delta L^{*2}}{(3s_{L^*})^2}} \qquad \text{Eq. (1)}$$

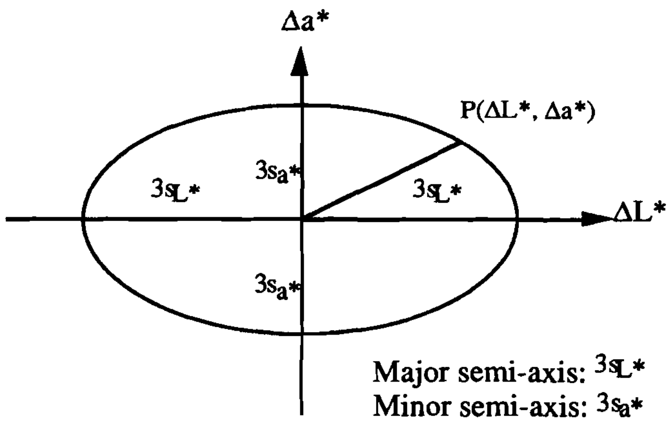

Figure 3. Computing the ΔL^* Δa^* plane using the ellipse formula.

C. Display the color variation ellipsoid in three dimensions using JMP

1. Import the ΔL* Δa* locus and ΔL* Δb* locus into a JMP worksheet as shown in the first five columns of Figure 4.
2. Build the last three columns (dL*, da*, db*) of the worksheet as shown in Figure 4. They represent two loci which model the color variation ellipsoid in question.
3. Provide a common scaling factor for proportional display.
4. Display the ellipsoid in three dimensions as shown in Figure 4.

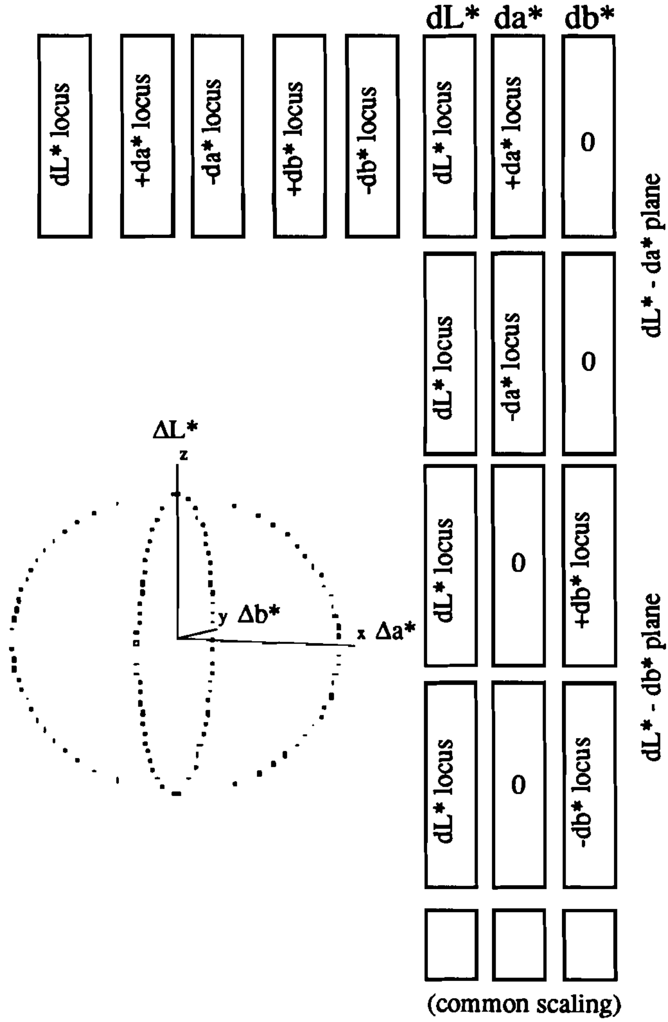

Figure 4. A description of the worksheet and an ellipsoid in JMP.

D. Enhance the 3-D Spin Display in JMP

1. There are 16 different colors and a variety of graphical marks which can be assigned to each data point to add information in the visual display. For example, colors which are redder then the average are displayed in red. Figure 5 shows how colors are assigned based on the angular orientation of data in the CIELAB color space.

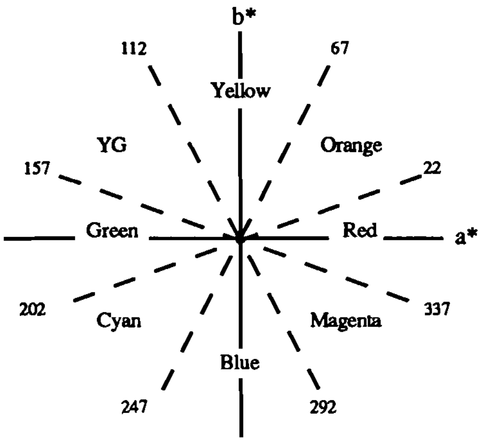

Figure 5. Adding colors to data points according to their angular orientations in the CIELAB color space.

2. When displaying the color tolerance data in 3-D spin mode, it is preferred that the ΔL* axis be situated vertically.
3. The ellipsoid which is made up by the ΔL* Δa* plane and the ΔL* Δb* plane can be displayed by itself or with data. Figure 6 provides an example of such a display with color.

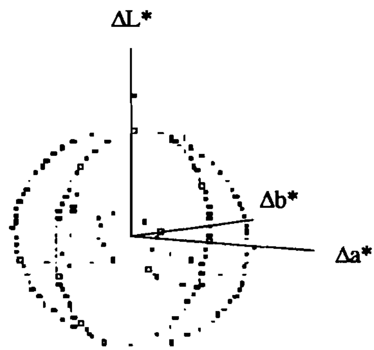

Figure 6. The ellipsoid and data are displayed together.

Case Study #1: Color Variation of Process Inks

A publication printer, with spectrophotometric measurement capabilities, collected 30 sample readings of the process ink set for a period of 12 months. Each set of readings represented a batch of inks received. The printer was interested in finding out (1) if the colorimetric average of all inks received agrees with internal ink standards closely, (2) what is a realistic color tolerance for each of the three process inks, and (3) how the color tolerance should be established.

Figure 7 illustrates color variation ellipsoids superimposed at the center of each process ink. The variation represents historical patterns of process ink variability. The degree of variation is suggested by the volume of the modeled ellipsoid. Here, the yellow process ink shows the smallest variation. Furthermore, the shape of the ellipsoid suggests which colorimetric dimension is most likely to vary. In this case, the magenta ink shows the greatest variation in the b* or yellow/blue dimension and the cyan ink shows the greatest variation in the a* or red/green dimension.

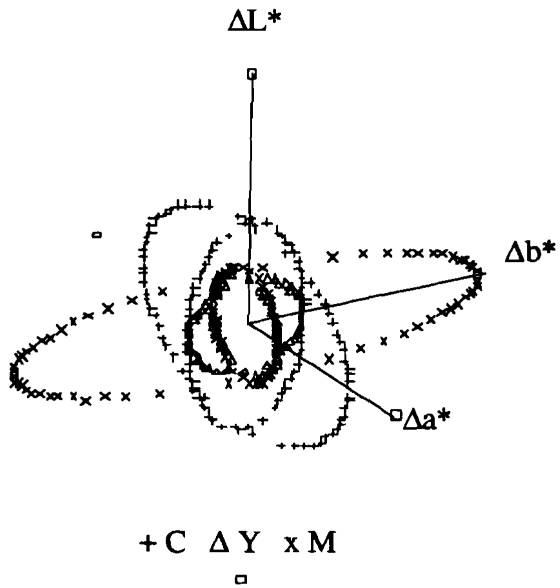

Figure 7. Cyan, magenta, and yellow variation ellipsoids.

It should be remembered that the above illustration is in motion and in color when displayed on a color CRT. It provides visual information that a two-dimensional black-and-white graph simply cannot.

Case Study #2: Color Variation of Single-color Printing

A print buyer purchases labels from printers located in a wide geographic region. To find out how consistent these labels are, a total of 100 samples were collected randomly and their colorimetric values recorded. Figure 8 illustrates the color variation ellipsoid of single-color printing in three dimensions. Notice that the major color variation is in the b* direction, which is the hue of the trademark color itself.

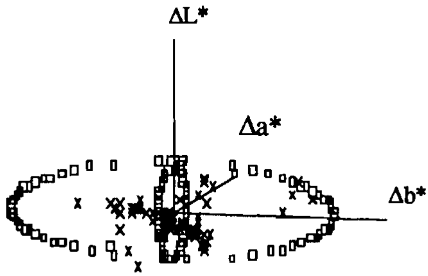

Figure 8. A color variation ellipsoid of a logo color.

Case Study #3: Color Variation of Process Color Printing

Process color printing uses cyan, magenta, and yellow plus black inks and halftone structures to reproduce colors of all hues, saturation, and lightness within its gamut capabilities. Once the color balance is achieved, three-color overprint tints were sampled and measured colorimetrically. Figure 9 represents 55 press sheets sampled from a sheet-fed offset press run. We can see that the shape of the variation ellipsoid is round, as opposed to being oblong in Figure 8. This is because changes in solid ink densities or dot gains in cyan, magenta, or yellow ink in a near-neutral patch will cause the hue to be shifted in just about any direction.

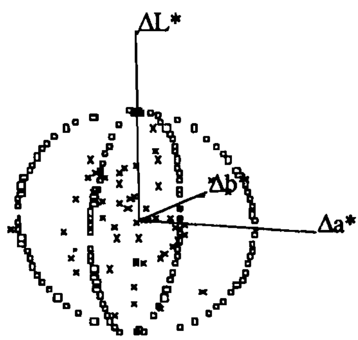

Figure 9. Color variation ellipse of process color printing based on three-color overprint tints.

Conclusions

Color variation has three dimensions. It is best described by an ellipsoid. Because of its three-dimensional spin capability, JMP proves to be an effective tool for visualizing color variation in the CIELAB color space. Without such a display, much information would be lost when color variations are described by three separate histograms or density ellipses.

Color variation of incoming inks can be characterized by the method described. Color variation of special color printing and process color printing can also be characterized by this method. Furthermore, the degree of color variation is signified by the volume of the modeled ellipsoid. The shape of the ellipsoid suggests the nature of the color variation with respect to the three colorimetric dimensions.

When selecting physical samples as standard, light limit, and dark limit, it's useful to make the selection based on the shape of the color variation ellipsoid. ΔE defines the magnitude of color difference between any two points. It is useful if the shape of the color variation ellipsoid is predominantly oblong, e.g., as with special color printing. In this case, ΔE can be estimated with the use of semi-axes in CIELAB color space, i.e.,

$$\Delta E = \sqrt{(ns_{L*})^2+(ns_{a*})^2+(ns_{b*})^2} \qquad \text{Eq. (2)}$$

where n = 1, 2, 3 and s_{L*}, s_{a*}, and s_{b*} are standard deviations of ΔL*, Δa*, and Δb* of data.

The use of physical samples is not recommended when the shape of the color variation ellipsoid is sphere-like, e.g., with the three-color overprint tints in process color printing. Too many samples would be needed to define the color tolerance boundaries, and they would make the method ineffective.

Further Studies

More work is needed to screen out outlier and to justify the number of standard deviations used in determining semi-axes of the ellipsoid. The size of the ellipsoid can be estimated by its volume. If the volume concept proves to be useful, then more work is also needed in rotating semi-axes such that they are orthogonal to the data set to have the best fit.

Color variation ellipsoids are constructed based on historical data. They represent the capability of the process or what has been received in terms of incoming inks. Color variation ellipsoids do not necessarily become color tolerances that print buyers specify. The use of this metric approach, however, should help color communication among print buyers, printers, and ink suppliers.

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