Gray Reproduction & Its Conformity Assessment

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Keywords: Gray balance, Gray reproduction, Characterization, Printing aims, Conformance

Abstract

ISO/TC130 is responsible for international printing standards development. Normative requirements for process control have been centered on solid coloration and TVI. Gray balance and gray reproduction are being addressed in the revision of ISO/WD1 12647-2 (2011). In this regard, the ISO/WD1 12647-2 (2011) takes paper color into consideration when defining gray reproduction aims, but there is a gap in the test method whereby only CIELAB values of the paper and the darkest CMY overprint solid are used to establish the gray reproduction ramp without knowing its relationship to the pre-determined near-neutral triplets and their colorimetric values. This paper takes a top-down approach to address the following issues: (a) what defines printed color, (b) how printing aims, such as gray balance and gray reproduction, are derived, (3) where does substrate correction come in, (4) how to assess gray reproduction of near-neutral triplets, and (5) how to assess gray reproduction conformance.

Introduction

What defines printed color?

Before we define printing aims, we need to define what defines printed color. Printing process control and color management primarily address 4-color CMYK reproduction. In this instance, printed color is defined by a color characterization data set, i.e., the relationship between CMYK tone values and their corresponding CIELAB values. Printing aims, e.g., solid coloration, TVI, or gray reproduction, are subsets of the characterization dataset. They are useful for press calibration and printing process control. So, a characterization data set defines printed color. In turn, it defines printing aims. The characterization data set and printing aims are inseparable.

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Process control versus color conformance

When printing conforms to process control aims, printed color may or may not conform to a characterization data set. This is because printing aims represent a small subset of a characterization data set. In other words, when solid coloration, TVIs of individual CMYK channel, and gray reproduction of CMY triplets are in conformance, many high TAC colors, influenced by ink transparency and ink trapping, may not conform to the printing condition that defines the data set. This is why device link, a color management solution, offers an extra degree of control to allow a repeatable printing process conform to a target characterization data set.

Should gray reproduction be a conformance requirement?

The starting point for discussing gray reproduction should be colorimetry. As we know, colorimeter is a tool for color management and densitometer is a tool for printing process control. Today, solid printing aims are defined in terms of CIELAB values with tolerances in ΔE^*ab. TVIs are defined by the Murray-Davies formula using tristimulus XYZ values per ISO 13655 (2009). Gray reproduction conformance is defined in chromaticness, or ΔCh, per ISO/WD1 12647-2 (2011).

Gray reproduction has only been recognized as an informative requirement in ISO/WD1 12647-2 (2011). As more and more gray reproduction use cases develop, chromaticness, or ΔCh is likely to replace the midtone spread as a normative requirement in the future revision of printing standard.

Literature Review

In this section of the paper, key terms, like gray balance, gray reproduction, gray reproduction ramp, and chromaticness, are defined. These terminologies are used to explain why there is a gap in the test method. They are also used to devise a complete test method to improve the usability of the ISO 12647-2.

Gray balance is tone value input

Similar to the relationship between CMYK tone value and color, gray balance and gray reproduction are input-output related. In this case, gray balance is a set of input CMY tone values that appears neutral under specified printing and viewing conditions. For the convenience of studying gray reproduction, near-neutral triplets, also known as pre-determined CMY triplets, are found in digital control targets, e.g., the IDEAlliance 12647-7 Digital Control Strip, Ugra/Fogra Media Wedge, G7 P2P25X target, etc.

Gray reproduction is chromaticness output

Gray reproduction is a set of colorimetric values of the printed CMY triplets. If the CIELAB values of the CMY triplets are derived from the aim characterization data set, these CIELAB values are colorimetric aims of the triplets. If the CIELAB values are measured from printed CMY triplets, then these CIELAB values are sample values. The gray reproduction is specified in Eq. (1) and Eq. (2) (ISO/WD1 12647-2, 2011).

$$\Delta L = L_1 * - L_2 * \qquad \text{Eq. (1)}$$

$$\Delta C_h = \sqrt{(a_1 * - a_2 *)^2 + (b_1 * - b_2 *)^2} \qquad \text{Eq. (2)}$$

Gray ramp is limiting

ISO/WD1 12647-2 (2011) defines the gray ramp, based on the color of the printing paper and the L* of the darkest CMY neutral a printing device can achieve, according to Eq. (3).

$$a* = a*_{paper}\left(1 - 0.85\frac{L_{paper} * - L*}{L_{paper} * - L_{cmy} *}\right) \qquad \text{Eq. (3)}$$

$$b* = b*_{paper}\left(1 - 0.85\frac{L_{paper} * - L*}{L_{paper} * - L_{cmy} *}\right)$$

The construction of the gray ramp is based on only two end-points of the gray reproduction ramp. The relationships between the pre-determined CMY triplets and CYM triplets falling on the gray reproduction ramp are unknown. As such, there is a gap in the test method in ISO/WD1 12647-2 (2011).

Methodology

The flow chart below illustrates a test method for gray reproduction assessment (Figure 1). It assumes that a digital target containing pre-determined near-neutral triplets, a target characterization data set and its ICC profile are available. It further assumes that a printing process has been calibrated and printed samples containing pre-determined near-neutral triplets measured. A step-by-step description of the test method for gray reproduction assessment follows:

1) Inspect tone values of pre-determined near-neutral triplets.

2) Find CIELAB values of the triplets via a target ICC profile.

We can identify colorimetric values of pre-determined gray balance triplets via the A2B LUT of the target ICC profile in an application program, e.g., Adobe Photoshop or ChroMix ColorThink 3 Pro.

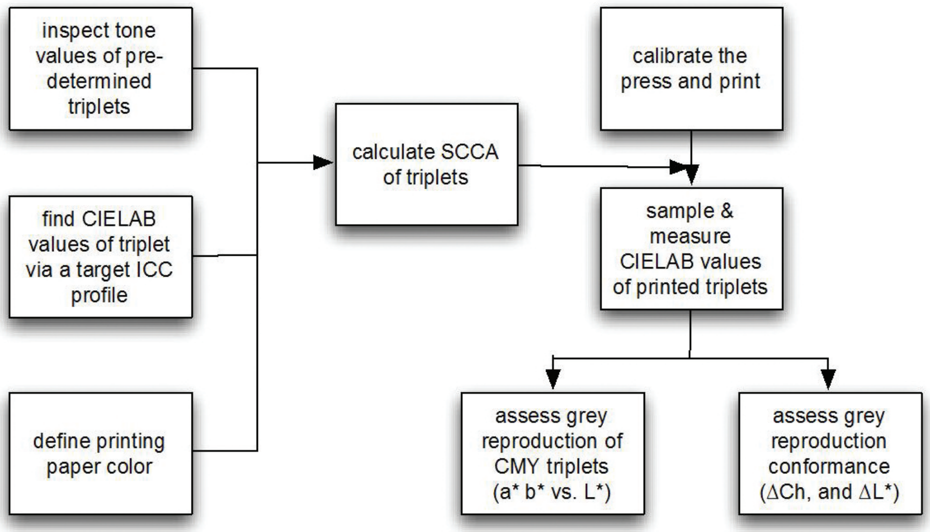


Figure 1. *Flow chart for assessing gray reproduction*

3) Define the production paper color.

4) Calculate substrate-corrected colorimetric aims (SCCA) of the triplets

If the production paper is different than the paper that defines the characterization data set, colorimetric aims of solids and gray reproduction need to be corrected accordingly. The substrate-corrected colorimetric aims, i.e., from $Paper_1$ (as defined in the data set) to $Paper_2$ (production paper), can be implemented via the tristimulus linear correction method, or Equation 4 (ISO 13655, 2009).

$$X_2 = X_1(1+C) - X_{min}C$$

$$C = \frac{X_{w2} - X_{w1}}{X_{w1} - X_{min}} \qquad \text{Eq. (4)}$$

To explain, color printed on $Paper_2$ (or X_2) is equal to the colorimetric values of color printed on Paper1 (X_1), times the slope (1+C), and subtract the constant ($X_{min}C$). The quantity, X_{min}, is the minimum tristimulus values of TAC_{Max} printed on $Paper_1$. The computational procedures are described below:

a) Given printing aims on the known substrate ($Paper_1$) and color of the new substrate ($Paper_2$) in CIELAB space,

b) Convert $CIELAB_1$ to $CIEXYZ_1$

c) Calculate the quantity, C, for X, Y, and Z using CIEXYZ of $Paper_1$, $Paper_2$, and Xmin

d) Convert $CIEXYZ_1$ to CIEXYZ2 by Eq. (4), and

e) Convert the substrate-corrected $CIEXYZ_2$ back to $CIELAB_2$ space.

Notice that Eq. (4) can replace Eq. (3) because both are based on the color of the printing paper and the darkest L* the CMY triplet can achieve. To construct a gray ramp using Eq. (4), the first substrate is where the ideal gray ramp begins from 100 L* with 0 a* and 0 b*, and the second substrate is the printing paper.

5) Calibrate the press and print the job.

   Press calibration methods, described in the ISO/TS 10128 (2009) including TVI, gray balance, and device link, may be applied. Details of each calibration method are omitted because press calibration is not the focal point of this paper.

6) Sample and measure CIELAB values of printed triplets.

7) Assess gray reproduction of near-neutral triplets (a* and b* vs. L*), and

8) Assess gray reproduction conformance (ΔCh and ΔL*) of the job.

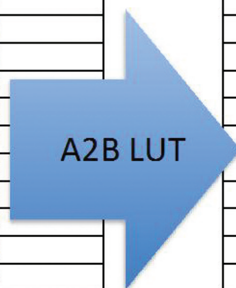
Results and Discussions

This paper is aimed at developing a gray reproduction test method to improve the usability of the ISO 12647-2. Therefore, the results are in the form of examples to show how each step is carried out and key findings in assessing gray reproduction of near-neutral triplets and gray reproduction conformance of the job.

Assessing gray reproduction of near-neutral triplets

The first step is to find colorimetric aims of these CMY triplets via the reference ICC profile under the absolute colorimetric rendering intent (Table 1).

C	M	Y	K
0	0	0	0
2	1.2	1.2	0
3.9	2.8	2.8	0
5.9	4.3	4.3	0
7.8	5.5	5.5	0
10.2	7.5	7.5	0
14.9	11	11	0
20	14.9	14.9	0
25.1	18.8	18.8	0
30.2	23.1	23.1	0
34.9	27.1	27.1	0
40	31.4	31.4	0
45.1	35.7	35.7	0
49.8	40	40	0
54.9	45.1	45.1	0
60	50.2	50.2	0
65.1	55.3	55.3	0
69.8	60.4	60.4	0
74.9	65.9	65.9	0
80	71.8	71.8	0
85.1	78	78	0
89.8	84.3	84.3	0
94.9	92.2	92.2	0
98	96.9	96.9	0
100	100	100	0



L*	a*	b*
95.37	0	-1.98
93.87	0.01	-2.21
92.16	0.2	-2.13
90.48	0.34	-2.04
89.04	0.24	-2.19
87.06	0.38	-1.98
83.42	0.38	-1.82
79.57	0.32	-1.62
75.81	0.11	-1.52
71.88	0.19	-1.45
68.4	0.21	-1.47
64.72	0.19	-1.51
61.17	0.04	-1.55
57.84	0.04	-1.35
54.11	0.1	-0.92
50.43	-0.04	-0.64
46.81	-0.26	-0.62
43.31	-0.19	-0.55
39.62	-0.35	-0.63
35.93	-0.53	-0.66
32.33	-0.43	-0.48
29.19	-0.18	-0.3
25.98	0.16	-0.15
24.22	0.12	-0.23
23.09	0.13	-0.25

Table 1. *Finding colorimetric aims for the near-neutral triplets via the reference ICC profile*

Table 1 illustrates the 25 steps of pre-determined near-neutral triplets from the P2P target as input (left-hand-side of Table 1). Colorimetric values (right-hand-side of Table 1) of these triplets are obtained in ChroMix ColorThink 3 Pro via the ISOCoatedeci_v2 ICC profile and the absolute colorimetric rendering intent. As a quick verification, the first row (0C/0M/0Y/0K) is paper and its CIELAB value is the color of the Type 1 paper (95.37L*, 0a*, -1.98b*)

The second step is to plot the graph of a* and b* versus %dot (cyan) of these near-neutral triplets (Figure 2). Notice that CIELAB values of the paper (0a*, -2b*) define the starting point of the gray reproduction ramp. The %dot (cyan) in the x-axis may be replaced by L* of the triplets.

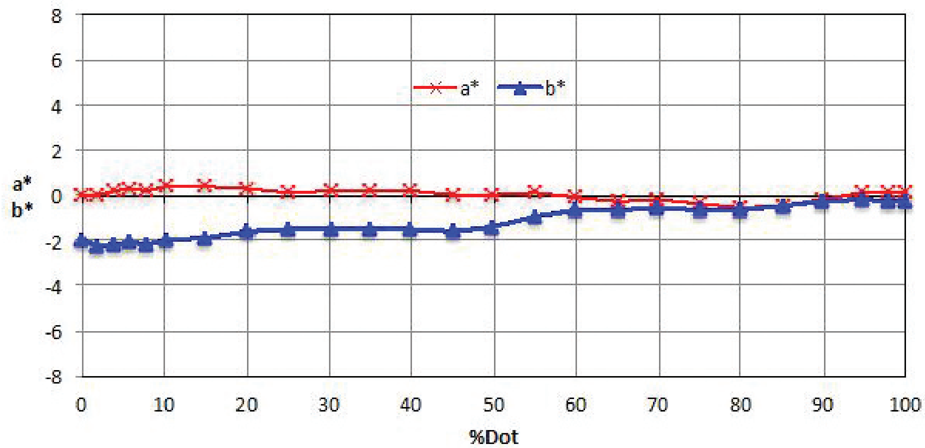


Figure 2. *Graph of a* and b* versus %dot (cyan) of the triplets*

The third step is to recognize the color of the production paper, e.g., Sappi McCoy Gloss (2.3a*, -8b*), and adjust colorimetric aims of the near-neutral using Equation (4). Figure 3 illustrates the graph of a* and b* versus L* of the triplets before (0a*, -2b*) and after (2.3a*, -8b*) the substrate correction.

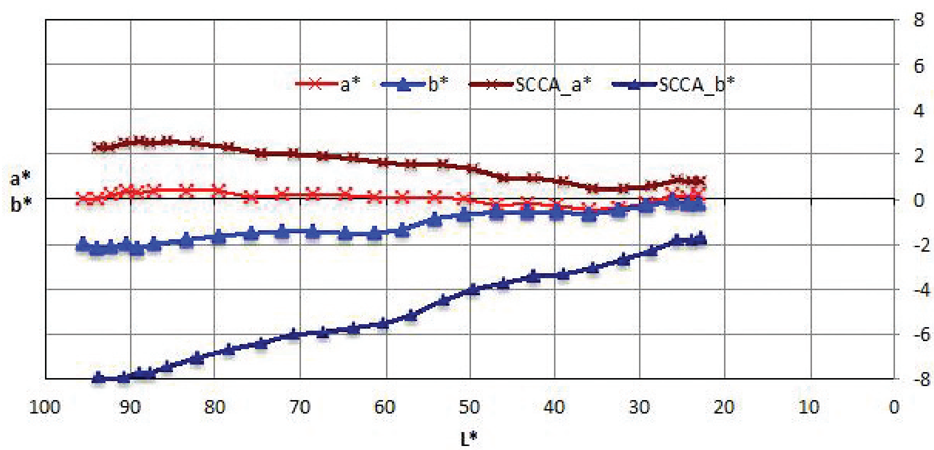


Figure 3. *Graph of a* and b* versus L* of the triplets before and after the substrate correction*

Notice that a* and b* values of the pre-determined triplets do not follow the straight-line between CIELAB values of the paper and CMY overprint solid. In other words, the gray reproduction ramp, as specified in the ISO/WD1 12647-2 (2011), does not represent colorimetric aims of the near-neutral triplets. Interpreting CIELAB values of the triplets through the reference ICC profile, described in the paper, overcomes the gap.

There are noticeable changes in printing aims when we apply substrate correction to the characterization data set. If the printing substrate contains OBA, the substrate-corrected cyan solid aim and magenta solid aim will have different hue angles, and the substrate-corrected yellow solid aim will have less chroma (TAGA, 2011). If there is a lightness difference between the data set and the production paper, the ΔL* will diminish as the near-neutral triplets darken. If there is a chromatic difference between the two papers, the magnitude of Δa* and Δb* of near-neutral triplets will diminish as the near-neutral triplets darken. In addition, there is no change between dataset-based TVI and substrate-corrected TVI (If any, there is less than one-half of one percent TVI change in the cyan channel). The reason that TVI is not affected by substrate correction is because (a) the tristimulus correction is linear in CIEXYZ space, and (b) the TVI is calculated by ratios of relative reflectance values (minus paper) between tint and solid.

Figure 4 illustrates how measured triplets (at six tone values) compare with the substrate-corrected aims of these triplets. To explain, the plot of a* and b* as a function of L* at the far left is the paper. Thus, the paper measurement and the substrate-corrected aims should align with each other. The closer the measured triplets are plotted to the aims, the more accurate is the gray reproduction. While highlight and midtone are often aligned closely by the gray balance based press calibration, measured triplets in the shadow often do not converge. Causes of the non-convergence of the CMY overprint solids, as mentioned earlier, include ink transparency and ink trapping. Figure 4 also illustrates that larger production deviation and variation are evident as tonality darkens.

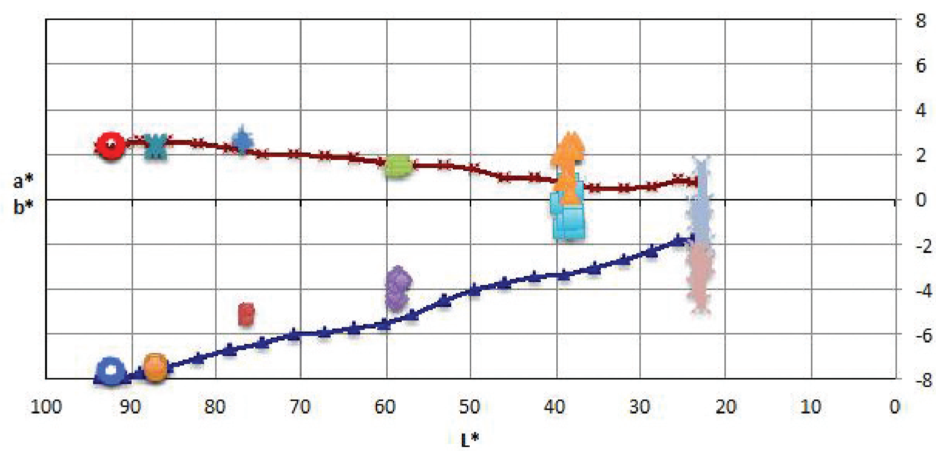


Figure 4. *Measured triplets vs. substrate-corrected aims*

The gray reproduction triplets can also be expressed in a* b* diagram (Figure 5). The line segment is the distance between the substrate-corrected a* b* values and the average a* and b* of 10 samples. CMY triplet starts from the paper color (2.3 a*, -7.9 b*) and migrates linearly towards (0 a*, 0 b*) as the tonality darkens. The shorter the line segment is, the smaller the ΔCh is, and the better the gray reproduction.

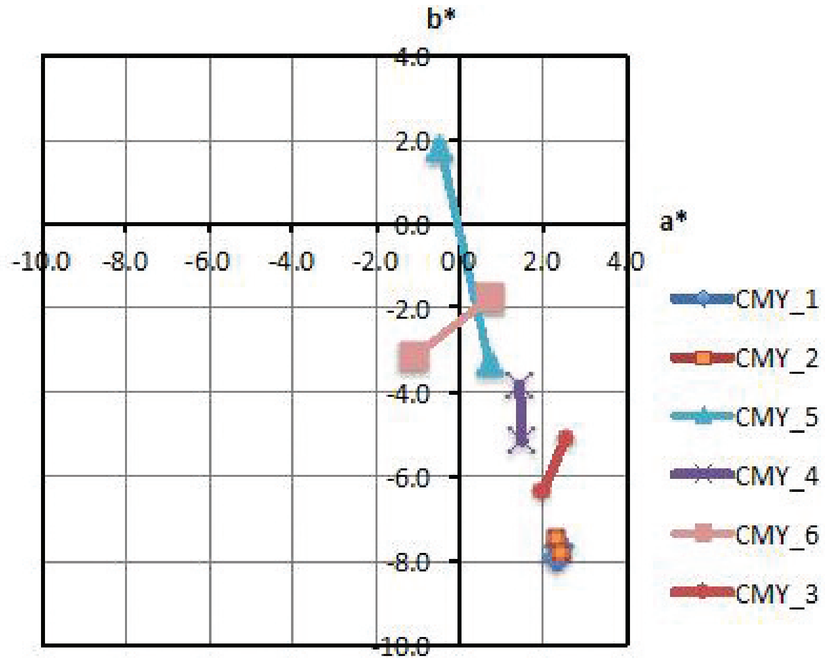


Figure 5. *Gray reproduction triplets in an a* b* diagram*

<u>Assessing gray reproduction and its conformance</u>

So far, we have described a test method of using near-neutral triplets to find their colorimetric aims from the target data set, calculating their substrate-corrected colorimetric aims, and calculating ΔL* and ΔC_h between their substrate-corrected gray reproduction aims and sample measurements. We recommend this test method to ISO 12647-2 for deviation and variation assessment. This requires that ISO 12647-2 define characterization data sets that are aligned with ISO 12647-2 printing aims.

An Excel spreadsheet, RIT_SCCA_Calc_v5, is included, along with the paper, in the DVD version of the Proceedings. The software is free. User takes full responsibility of its use. To get the substrate-corrected colorimetric aims (SCCA), input the required information in the input fields (highlighted in yellow), i.e., selection of dataset, paper color measurement, and customized input dataset, if applicable. In the output fields, SCCA of all dataset, 9 patches, gray reproduction, and TVI values are derived.

While many near-neutral triplets are desirable when calibrating a press, three triplets are believed to be sufficient to assess gray reproduction conformity. Table 2 is an example of using three pre-determined triplets, at quartertone (25C/19M/19Y), midtone (50C/40M/40Y), and three-quarter tone (25C/19M/19Y), as input requirements. Tolerances are configured in three levels, i.e., stringent, normal, and relaxed, to account for process capability and application requirements. The tolerance for the normal level was determined based on a study of IDEAlliance G7 database (RIT, 2011). Tolerances for the stringent and the relaxed, not available in the G7 database, have only been tested with limited use cases. Thus, Table 2 represents a reasonable starting point and further deliberation is required.

Grey	Tolerance Level (ΔC_h)			Tolerance Level (ΔL^*)		
Reproduction	Stringent	Normal	Relaxed	Stringent	Normal	Relaxed
25C/19M/19Y	1.5	2.0	3.0	1.5	2.5	3.5
50C/40M/40Y	2.0	3.0	4.0	1.5	2.5	3.5
75C/66M/66Y	3.0	4.0	5.0	1.5	2.5	3.5

Table 2. *Example of a multi-level gray reproduction tolerance*

Further work

The gray reproduction tolerances may be determined by simulation whereby printed samples having midtone spreads (S) greater and less than '5' are compared with chromaticness values (ΔCh) collected from the same database with the use of an optimization method (Berns, 2000). The topic is an on-going thesis project at RIT.

A related research is to use substrate-corrected colorimetric aims for printing and proofing to evaluate print-to-proof visual match while printing paper containing OBA and proofing substrate does not. This is another on-going thesis project at RIT.

Conclusions

This paper points out a gap in the ISO/WD1 12647-2 (2011) whereby only CIELAB values of the paper and CMY overprint solid are used to establish the gray reproduction reference without knowing its relationship with the pre-determined near-neutral triplets. The method, described in the paper, overcomes such a gap by utilizing pre-determined near-neutral triplets and the reference ICC profile to establish the gray reproduction aims, and followed by substrate-correction.

This paper further points out that there is a difference between the number of triplets needed for press calibration and the number of triplets needed for gray reproduction conformance assessment. Only three triplets, at quartertone (25C/19M/19Y), midtone (50C/40M/40Y), and three-quarter tone (25C/19M/19Y), are needed for gray reproduction conformance assessment.

Acknowledgment

The author wishes to recognize Mr. David McDowell for his advice and encouragement in printing standard development activities. He also wishes to recognize Mr. Ping-hsu Chen for his programming supports and collaboration.

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