A Quantitative and Qualitative Assessment of the Impact of the Number of Patches Included in Profiling Targets.

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Abstract: This paper examines the impact of the number of color patches included in profiling targets on the subjective and objective quality of a printer profile. The subjective quality is assessed through qualitative means that examine whether a color difference is visually perceptible. The objective quality is assessed through quantitative means that examine the colorimetric accuracy of the profile. A paired comparison test is used in the former case and cumulative frequency distribution curves and nonparametric statistics are employed to assess the latter. This paper provides insight into to perceptibility of total color difference and on the creation of ICC profiles. The result of both assessments is that there is no significant difference between the different size profiling targets. The differences between the created profiles are nonetheless discussed without regard of statistical significance.

Introduction

The purpose of this paper is to provide insight into the implementation of International Color Consortium (ICC) color management, in particular, on the targets that are used in the creation of profiles. Lately, profiling software developers, as well as national and international organizations, are creating targets with an increasing number of patches. For example, the latest version of IT8.7/4 (ANSI, 2005) has 1617 patches, whereas the full set of IT8.7/3 has 928 patches.

Does the number of patches has a significant impact on the subjective and objective quality of the ICC profile that is created, and is there any perceptual and colorimetric significant difference in the results obtained from each profiling target?

It is reasonable to think that an ICC profile created with a profiling target that has a larger number of patches will provide more information during the construction of the profile; this should result in less interpolation when the multidimensional look up table (CLUT) is mapped and thereby produce higher colorimetric accuracy. The inclusion of more patches is meant to sample the device's color space in more detail, especially at the low and high L* ranges (ANSI, 2005), and avoid any artifacts that may be caused by inaccurate interpolation.

Colorimetric accuracy, however, does not always mean that the effect of the profile on a pictorial image will result in a better perceptual result. Moreover, some degree of interpolation might be beneficial and may result in a smoother gradation of the tonal value reproduction.

Additionally, there are a number of workflows that call for a solution with fewer color patches; in commercial web offset printing and publishing, it is necessary to create profiles for each press and each paper grade. This entails a delay in the production, which translates into higher costs. A possible solution would be to perform the ICC profiling press run during the actual production time—utilizing the capabilities of closed loop color control systems—by placing the patches of a profiling target as a color bar laterally on the printing plate. The constraint of this scenario is that there is usually not enough available space on the plate for the patches. If fewer swatches can provide sufficient information to build a reliable ICC profile, then this would be a reasonable solution.

The performance of all the profiles will be evaluated both subjectively (by comparing the output pictorial image) and objectively (by measurement of control elements). Additionally, color vignettes will be visually evaluated in order to observe the behavior of the profile. As described in ISO/WD 12640-3.4 (2004), the test images will include both natural scenes (pictures) and synthetic images (color charts and vignettes). The results of the subjective image evaluation are strongly affected by the image content. As such, an image with a variety of skin tones and an image with near neutral colors were selected. This selection omits the full range of the color gamut, which can only be evaluated by utilizing synthetic color charts and vignettes.

Literature review

The basic reasoning that underlines this experiment is that a profile that accurately describes the behavior of the press and results in satisfactory reproductions does not depend solely on the number of patches that the target contains. The level of detail that is engineered in the construction of the CLUT and the Color Management Module (CMM) that performs the interpolation, are significant factors that can improve the profile's performance. A CLUT with a large number of entries can accommodate a small number of patches and the CMM, by interpolating between the input values and the Profile Connection space (PCS), can create reliable profiles. If the printer has a well-behaved and consistent response (Sharma, 2004), this objective can be achieved through linearization of its tonal value reproduction and using a small number of patches only. A large number of patches may actually result in posterized images, whereas a less accurate target that "distorts colors slightly may produce smooth transitions between tones and colors" (Fraser, Murphy, & Bunting, 2005). Furthermore, the systematic increase at fixed intervals of the percentages of the CMYK colorants that make up the profiling target may result in clustering of the CIELAB values of the printed target. This clustering creates the effect of an uneven distribution of the tonal reproduction curve resulting in reproductions where the gradation is not smooth (Brydges, 2005; Hutcheson, 2005).

The Western Michigan University Profiling Report (2005) discusses the round-trip approach as a means of evaluation of colorimetric accuracy. The round-trip approach performs the conversion of CIELAB values to CMYK and then back again to CIELAB. In other words, colorimetric accuracy is assessed as the ability to reverse the profile look-up tables with the device repeatability factor excluded.

The choice of nonparametric statistics and Cumulative Relative Frequency (CRF) curves was made due to the lack of normality of the ΔE^*ab distribution.

The total color differences can only be greater than zero and the distribution is usually skewed or asymmetric (Berns, 2000). Under certain assumptions, parametric statistics may be used, but the restriction applied is that there can be no determination of probability, since the distribution is skewed (Fisch & Bartels, 1999). Chung & Shimamura (2001) propose the use of cumulative relative frequency distributions. This approach eliminates the bias due to the asymmetrical distribution of total color differences. The number of samples is sorted in ascending order based on the magnitude of their ΔE^*ab and their rank order is calculated.

Nonparametric statistics provide an alternative solution. The Kruskal-Wallis Test can be used to test whether two or more populations are identical (Anderson, Sweeney, & Williams, 2005). The test assumes that the populations are independent and that their distribution need not be normal. The scales of the data should be at least ordinal. Under the null hypothesis that the populations are identical, the sampling distribution W can be approximated by a chi-square distribution with k–1 degrees of freedom. The approximation is constrained for sample sizes of $n \geq 5$. The procedure uses an upper tail test and the null hypothesis is rejected when the test statistic is smaller than the critical p-value. The test statistic is calculated by Equation (1):

$$W = \left[\frac{12}{n_T (n_T + 1)} \sum_{i=1}^{k} \frac{R_i^2}{n_i} \right] - 3 (n_T + 1) \quad (1)$$

where
k = the number of populations
n_i = the number of items in sample i
$n_T = \Sigma n_i$ = the number of all samples
R_i = sum of the ranks for sample i

It should be mentioned that statistical significance does not necessarily correlate with the perceptibility of total color differences. In other words, it cannot be determined whether two sample sets that do not have a statistically significant difference between their medians do, in fact, differ perceptually. For example, a difference of 1.50 ΔE^*ab may not be considered statistically significant, but it may result in a perceptual difference. For that purpose, the results of this experiment will also be evaluated without reference to statistical significance.

Objectives

To determine whether the number of patches included in a profiling target has a significant impact on the colorimetric accuracy of the profile. To determine whether the number of patches included in a profiling target has a significant impact on the perceptual quality of the profile.

Equipment & Target Forms

Kodak Approval NX
ProfileMaker 5.0
Measure Tool 5.0
Spectrolino & Spectroscan
MATLAB 7.0
Mac OS X
ColorThink 1.2
Microsoft Excel 2003
Adobe Creative Suite 2
Targets: IT8.7/3 - Full set (928 patches), IT8.7/3 - Basic set (182 patches), IT8.7/4 - Visual (1617 patches), TC 3.5 CMYK (432 patches), IT8.7/3 Adjusted - Reduced with an addition of a gray bar (91 patches), N4A SCID IMAGE, N7A SCID IMAGE, TAC RIT chart, CV2 – CIELAB vignette reduced color gamut CIELAB/SCID

Experimental Procedure

Apart from the four ICC profiling targets that are displayed in the 'Targets' section above, an additional target, 'IT8.7/3 Adjusted', was created based on the basic set of IT8.7/3. The 'IT8.7/3 Adjusted' target was created by first removing columns G through N from the basic IT8.7/3 target and then replacing column G with a CMY gray balance target. For reference, patch G12 was set to CMY= 10%. The target is displayed in Figure 1.

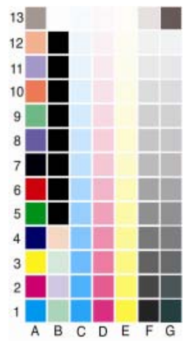


Figure 1. IT8.7/3 Adjusted target with 91 color patches and a grey balance bar.

The basic and adjusted sets of IT8.7/3 are not normally used as profiling targets and the data of the reference set for the creation of the profile had to be edited from the reference text file of the full IT8.7/3. The profile was opened in a text editor and the values of the full set that were not included in the basic set were deleted. The indexing (A1, A2, …K13) was changed to match to the values of the reference and sample sets. Even if these targets do not sample the entire color space of the device, they are assumed to provide a fair amount of data points for the gamut boundaries, colorant combinations, and gray balance. It is expected that if the tonal reproduction behavior of the printer is linear over the tonal range, interpolation will be able to create a good profile.

The five profiling targets, along with the TAC RIT chart, were placed in an Adobe InDesign CS2 document with the color management option turned off and were printed on the Kodak Approval NX with 150 lpi resolution. The paper that was selected was the same that was used in Test Targets 5.0 publication of the School of Print Media at RIT; this allows for the pictorial images to be referenced to the images printed in the publication. The printed targets were measured and ICC version 2 profiles were created in ProfileMaker v5.0 with the settings displayed in Figure 2. The Total Area Coverage (TAC) was chosen based on the CMYK combination of the TAC RIT chart that resulted in the blackest patch achievable with the least amount of CMY.

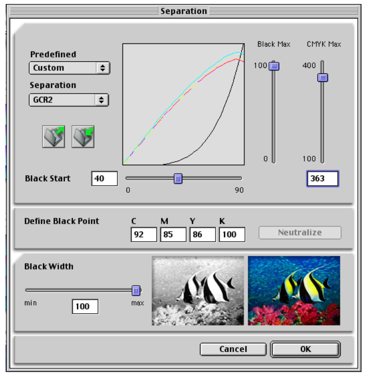


Figure 2. GCR settings for the creation of the profiles. The Max CMYK value was selected based on the TAC RIT chart.

The color gamut of the profiles is displayed in Figures 4–6. Figure 3 displays the colors that were selected for the display of each profile; the color gamuts were plotted in ColorThink.

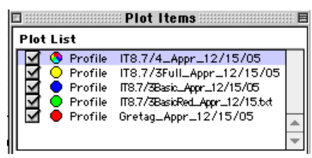
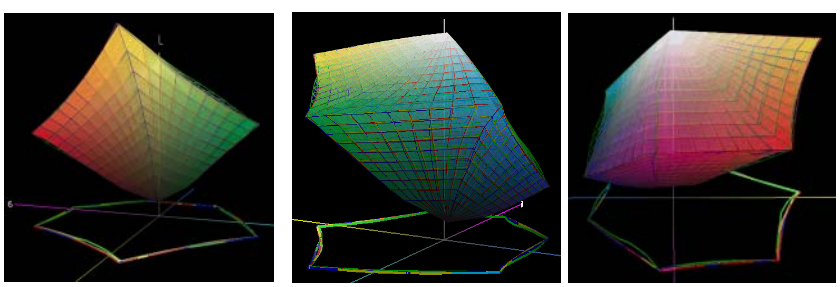


Figure 3. The color notation for the color gamuts of each profile.



Figures 4-6. The color gamuts of each profile, as displayed in ColorThink.

Overall, the gamuts of the profiles match, especially at their color gamuts. However, in Figures 4 and 6 it can be seen that the green wireframe representing the ‘IT8.7/3 Adjusted’ has a larger gamut due to interpolation. In Figure 5, the blue wireframe, representing the ‘IT8.7/3 Basic’ does not match with the rest.

For the quantitative assessment, the round-trip approach was used. This approach performs the conversion of CIELAB values to CMYK and then back again to CIELAB. The test charts that were used were a*b* slices at L* of 90, 70, 50, 30, and 10, with systematic increments of 20 a* and b* (Figure 7). The reproducible gamut of each profile was estimated with the Gamut Warning command of Adobe Photoshop. Each profile was set as the CMYK working space in the Color Settings and the Gamut Warning was turned on (Figure 8). It should be mentioned that the color gamut information does not have the highest detail due to the incremental nature of the a*b*slices, and there will be larger color differences at the gamut boundaries.

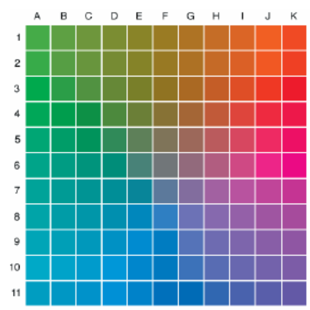


*Figure 7. a*b* slices of L*50, with systematic increments at 20 a* and b*.*

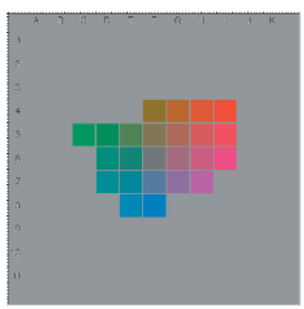


*Figure 8. a*b* slice at 50L* with Gamut Warning on for IT8.7/4 Visual profile.*

The digital CIELAB values of the patches of the a*b*slices were read through the 'LABReader' software program written in MATLAB by Jorge Uribe (Understanding black point compensation, 2005), and the Kruskal-Wallis test was performed both for the ΔE*ab values of the whole slice and only for the in-gamut colors, by a program written in MATLAB by the author. Additionally, CRF curves of the in-gamut colors and frequency distribution plots were created for the total color differences of the converted a*b*slices over the initial CIELAB values.

The two pictorial images were opened in Adobe Photoshop CS2 and were assigned the profile that was used in the Test Targets 5.0 publication. Then, they were converted with the absolute colorimetric intent to each of the profiles, resulting in 2 sets of 5 images, each with a different profile, for a total of 10. The vignettes were taken from ISO/WD 12640-3.4. The reduced gamut set was preferred, since the in-gamut colors are more significant for this evaluation.

The reproduced images were framed in a white background and were compared visually against the reference images from the Test Targets 5.0 publication. For the paired comparison test, ten pairs were required for each set of images, according to the formula N = (n * (n – 1)) / 2, where N stands for the number of pairs and n stands for the number of samples. One paired comparison test was made for the N7A pictorial image and one for the N4A. The size of each image was approximately 4 x 6 inches and the frame was 1.5 inch at each side. The images were displayed on a light booth under D50 at a fixed distance of approximately 50 cm. The observers were asked to do the paired comparison in terms of color matching to the reference image. Ten judges were used, students and professors from RIT's School of Print Media, who are considered to be trained on color theory. The images were displayed in a random order.

The evaluation of the paired comparisons and the construction of the interval scale was made under the assumptions of Thurstone's Law of Comparative Judgements (Bartleson, 1984), and especially Case V, that assumes that the dispersions are equal for all the stimuli (Equation 2).

$$R_i - R_j = \sqrt{} z_{ij} * \sigma * 2 \qquad (2)$$

where
R_i and R_j : scale values of stimuli i and j
Σ: discriminal value of both stimuli since their distributions are considered equal
z_{ij}: normal deviation corresponding to the proportion of times j is judged greater than i

According to the procedure explained by Montag (2005), a frequency matrix showing the number of times each stimulus was selected for each pair was constructed and the frequencies were converted to proportions. These were converted to z-scores and averaged for the interval scale. The confidence interval at 95% confidence was calculated based on Equation 3 that was presented by Montag in the Symposium on Electronic Imaging (2004).

$$R \pm 1.96 * \sigma_{pred} \quad (3)$$

where
$\sigma_{pred} = b_1*(n-b_2)^\wedge b_3*(N-b_4)^\wedge b_5$
n: the number of stimuli
N: the number of observations
$b_1 = 1.76$, $b_2 = -3.08$, $b_3 = -0.613$, $b_4 = 2.55$, and $b_5 = -0.491$

Results & Discussion

Quantitative Analysis

The first test of the quantitative analysis is the Kruskal-Wallis nonparametric test. The result was that there is no significant difference between the medians of the five profiles. The p-value for the in-gamut colors is 0.4518 > a = 0.05, at 95% confidence. The results of the out-of-gamut colors are identical, with a p-value of 0.9655. The results are shown in Table 1.

Table 1: Kruskal-Wallis ANOVA table. The test results for the in-gamut and out-of-gamut colors. No statistical significance at 95% confidence between medians.

In Gamut colors					
Source	SS	Df	MS	Chi square	Prob>Chi sq.
Groups	24742.1	4	6185.53	3.67	0.4518
Error	1934456.4	287	6740.27		
Total	1959198.5	291			
Out of Gamut colors					
Source	SS	Df	MS	Chi square	Prob>Chi sq.
Groups	440719.9	4	110180.0	0.58	0.9655
Error	2306138087.1	3020	763621.9		
Total	2306578807.0	3024			

The Statistics toolbox in MATLAB creates a boxplot of the medians of the five profiles, shown in Figure 9. The whiskers of the boxplot display the interquartile range, which is the difference between the 75th and 25th percentiles of the samples. If the whiskers overlap, there is no statistical difference between the medians of the five samples at 95% confidence. Since the medians are derived from total color differences, the sample with the lowest value is the one that has the least color difference, which in this case is the ‘IT8.7/3 Full’. Finally, it can be observed that there is a single value larger than 9.00 ΔE*ab at the measurements of ‘IT8.7/4 Visual’, which is seen as the red cross in the boxplot and should be considered an outlier.

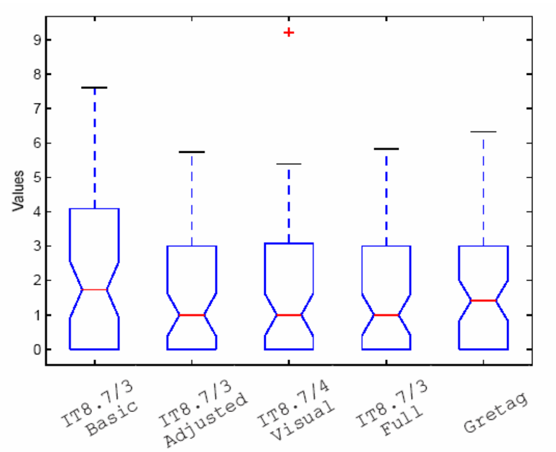


Figure 9: Boxplot of the total color differences that result from the 6 profiles. No significant difference.

Table 2 displays the descriptive statistics derived from the calculation of the ΔE*ab values. It can be observed that the distribution is identical for the samples, and that it is spread to the right of the mean; it is an almost normal distribution, since the skewness value is close to zero, except for the ‘IT8.7/4 Visual’ target that is spread out further. From the InGamut values it can be seen that the ‘IT8.7/3 Full’ has the best results, followed by ‘IT8.7/3 Adjusted’ and ‘IT8.7/4 Visual’, which however has an outlier in its sample.

Table 2: Descriptive statistics for the five profiles.

InGamut	IT8.7/3 Basic	IT8.7/3 Adj.	IT8.7/4 Vis.	IT8.7/3 Full	Gretag
mean:	2.31	1.70	1.68	1.61	1.75
median:	1.73	1.00	1.00	1.00	1.41
interquartile:	4.09	3.00	3.08	3.00	3.00
range:	7.62	5.74	9.22	5.83	6.32
std:	2.25	1.86	1.93	1.76	1.88
skewness:	0.68	0.75	1.37	0.77	0.83
kurtosis:	2.38	2.23	5.22	2.34	2.57
OutGamut	**IT8.7/3 Basic**	**IT8.7/3 Adj.**	**IT8.7/4 Vis.**	**IT8.7/3 Full**	**Gretag**
mean:	45.11	46.02	45.13	45.11	44.90
median:	44.61	45.99	45.06	44.52	44.65
interquartile:	42.84	41.77	41.41	42.78	42.49
range:	117.90	121.17	118.68	118.68	117.29
std:	27.48	27.59	27.52	27.60	27.54
skewness:	0.16	0.14	0.15	0.15	0.15
kurtosis:	2.25	2.28	2.25	2.24	2.24

Even if there are no significant statistical differences, the results obtained from each profile differ. The ΔE*ab values for each profile were grouped in intervals of 1.00 ΔE*ab from 0.00<0.99, 1.00<1.99, until the 6< range, and the percentages of the results that fell within each range were calculated. Figure 10 shows the results.

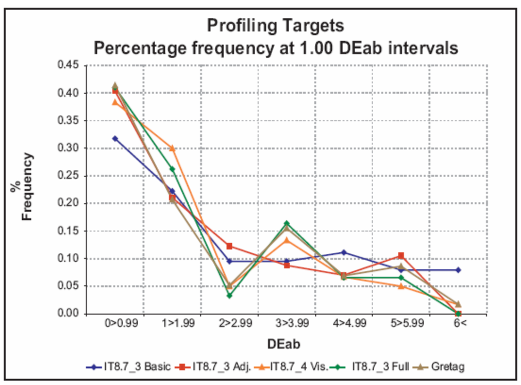


Figure 10: Percentage frequencies for the results of each profiling target.

This analysis is especially meaningful because the total color difference scale is not equal throughout its range. It can be observed that ‘IT8.7/3 Full’ and ‘IT8.7/4 Visual’ result in profiles with a higher percentage of color differences at the range of 0<1.99—where the color difference is less perceptible—and a smaller percentage at the higher ranges. Conversely, ‘IT8.7/3 Basic’ and ‘IT8.7/3 Adjusted’ have a smaller percentage of low colorimetric differences and a larger percentage of high colorimetric differences. Another observation is that the distribution is bimodal; the second peak occurs at the 3.00–3.99 range for 'IT8.7/3 Full', 'IT8.7/4 Visual', and TC3.5. This may be attributed to the round-trip error caused by the mapping of the patches that lie on the gamut boundaries of the device. These results can best be displayed if we group the percentages to the ranges 0–1.99, 2–5.99, and 6.00–6.00+ (Figure 11).

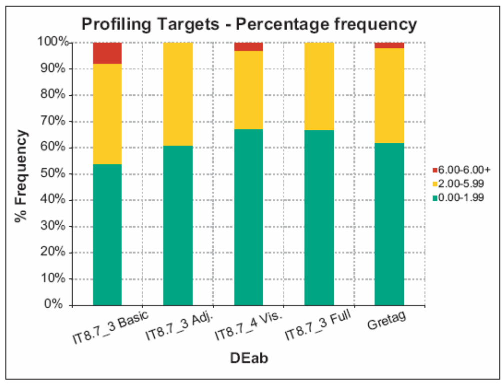


Figure 11: Grouped colorimetric differences.

The CRF curve (Figure 12) shows that over the entire range of ΔE*ab there is not a difference among the five profiles, with the exception of 'IT8.7/3 Basic' that displays slightly greater color differences. It could be assumed that the addition of a detailed CMY gray balance bar in the basic IT8.7/3 set had positive results to the colorimetric quality of the profile, despite the reduction of the color patches from 182 to 91 patches.

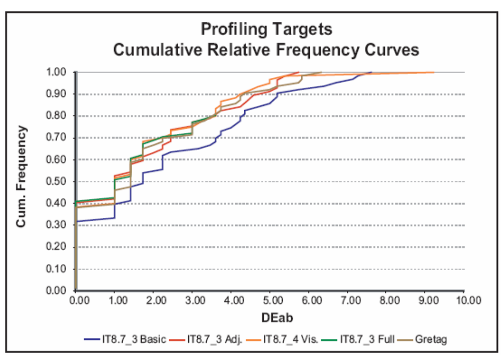
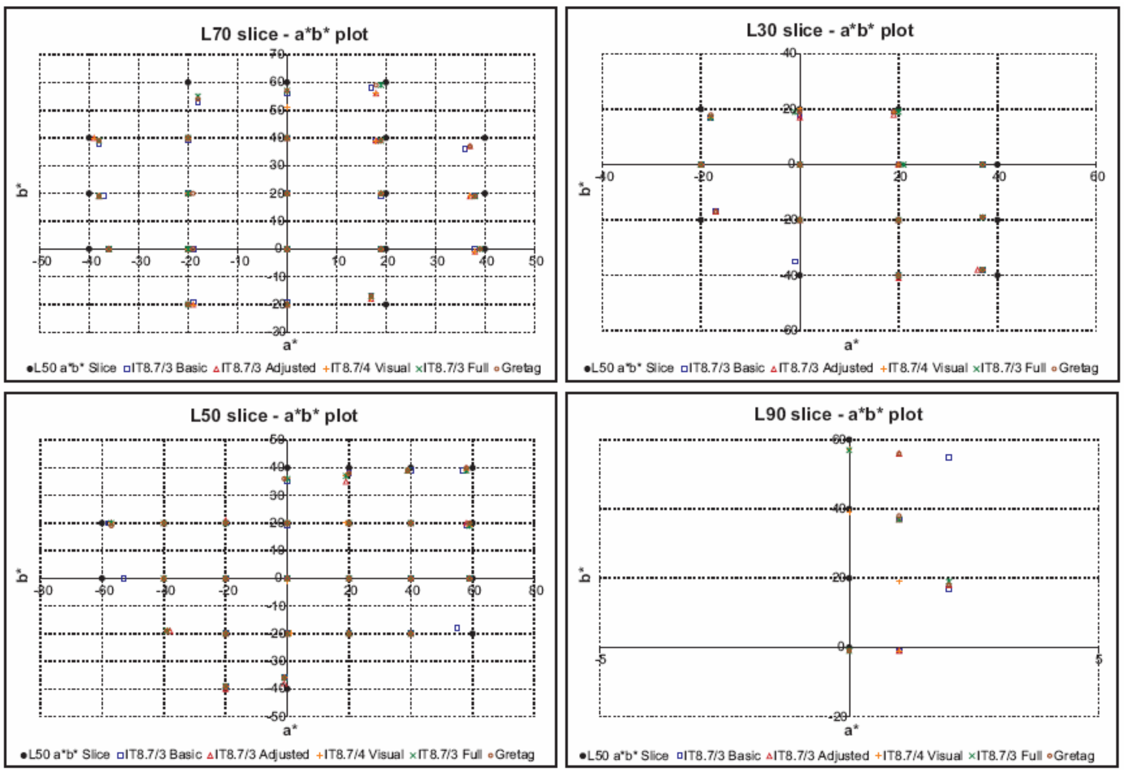


Figure 12: Cumulative frequency distribution for the results of each target.

Figures 13–16 (previous page) display the a*b* plots for the five profiling targets. It can be seen that they are all clustered around the reference a*b* values (seen as black dots). Moreover, the deviations from the reference that are closer to the gamut boundaries are larger.

The achromatic dimension is not considered in these plots, and as displayed in Figure 17, there is significant deviation from the target L* value. In Figure 17 only the L30 slice is displayed; the remaining slices had similar deviations.



*Figures 13-16: a*b* plots of the 5 targets, The data points are clustered around the target a*b* value.*

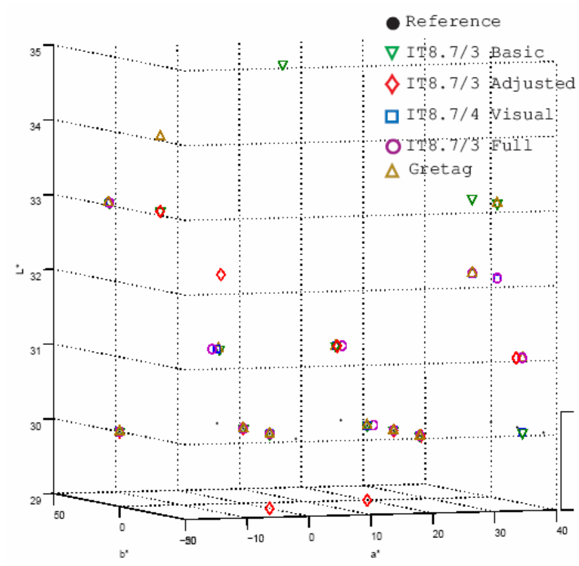


Figure 17: 3D plot (in MATLAB) of the L30 slice.

The observation of the vignettes did not prove to be as useful as initially expected, as the differences between the profiles were slight (Figure 18). Only the ‘IT8.7/3 Adjusted’ target can be said to be different, with slightly higher L* values; it can also be observed that each profile resulted in similar gradations. By looking at the entire color vignette target, only a few instances —‘IT8.7/3 Full’ and ‘IT8.7/4 Visual’— were slightly more detailed.

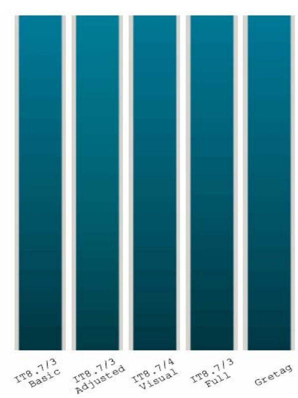
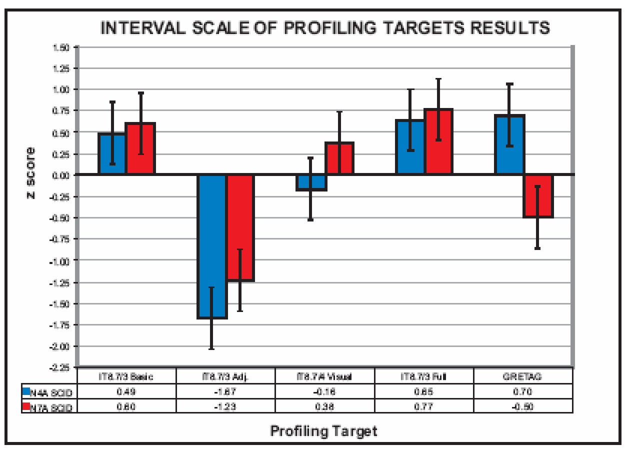


Figure 18: Color vignettes. Reduced set at hue angle of 270^o.

Qualitative Analysis

The images that were shown to the observers are displayed in Figures 19 and 20. N7A is the one on top, and N4A is the one on the bottom. The results of the paired comparison test are displayed with an interval scale in Figure 21.

Figures 19-20: SCID images N7A and N4A, left to right.



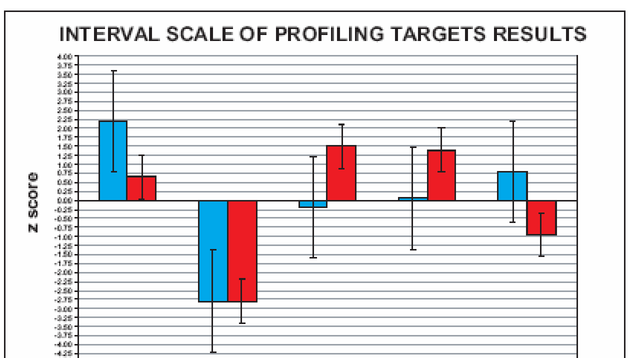
Figures 21: Paired comparison results. All judges included.

When interpreting the results, it is important to take into consideration the confidence interval, which was 0.36 at 95% confidence for n = 5 and N = 10, as calculated by Formula 3. In order for a result to be statistically significant, the confidence intervals should not overlap. According to Figure 21, the profile created by 'IT8.7/3 Adjusted' was significantly inferior for both images. The best profiles were the ones from the 'IT8.7/3 Basic' and the 'IT8.7/3 Full' sets.

The ‘IT8.7/4 Visual’ set was significantly worse than ‘IT8.7/3 Full’ only for N4A. ‘TC3.5’ was worse for image N4A; and it was equal to ‘IT8.7/3 Basic’, and ‘IT8.7/3 Full’ for image N7A.

Since the performance of each profile should be judged on a variety of images—and the performance of several targets was different for each image with relation to the rest—it could be said that the performance of the profiling targets is image dependent. Under this consideration it is important to do the test over a wider range of images, as suggested in ISO/WD 12640-3.4.

Subsequent analysis showed that a great number of judges had logical inconsistencies in their observations. Only 3 out of 10 judges for N4A, and only 5 out of 10 for N7A were consistent in their judgments. Their consistency was evaluated based on the concept of circular triads (Montag, 2004); a logical inconsistency occurs when, for example, stimulus A is judged better than B, and stimulus B better than stimulus C, but stimulus C is judged better than A. Elimination of the inconsistent judges for each image resulted in the results displayed in Figure 22. Note that the confidence intervals are increased for N = 3 and N = 5, resulting at values of 0.61 and 1.41 respectively at 95% confidence. For N4A there is no difference among the prints, with the exception of ‘IT8.7/3 Adjusted’, which is inferior to all of the targets, except ‘IT8.7/4 Visual’. For image N7A only the prints from ‘TC3.5’, and ‘IT8.7/3 Adjusted’ were significantly inferior.



	IT8.7/3 Basic	IT8.7/3 Adj.	IT8.7/4 Visual	IT8.7/3 Full	GRETAG
N4A SCID	2.19	-2.80	-0.18	0.05	0.79
N7A SCID	0.65	-2.80	1.50	1.40	-0.95

Figure 22: Paired comparison results after elimination of inconsistent judges.

Conclusions

There is no significant colorimetric difference among the profiles created from the five profiling targets, neither for in-gamut or out-of-gamut colors. Disregarding the statistical significance, 'IT8.7/4 Visual' and 'IT8.7/3 Full' were slightly better in terms of colorimetric accuracy. Observation of the color vignettes resulted in the same conclusion.

Taking into account the large number of inconsistent observers, it can be said that, with the exception of 'IT8.7/3 Adjusted', there is no significant perceptual difference among the profiling targets. The IT8.7 targets were the best for both images at a 95% confidence and, as such, it can be said that there is no perceptual difference due to the number of color patches included in the targets. Differences can be attributed to the sampling of the device's color space, as displayed by the difference in performance for Gretag's TC3.5 and the adjusted IT8.7/3 set.

There is a slight correlation between colorimetric accuracy and visual assessment, since 'IT8.7/3 Full' and 'IT8.7/4 Visual' performed better in both the qualitative and quantitative evaluation. This statement is not supported at 95% confidence.

Statistical significance and confidence intervals are valuable tools for the evaluation of profiles. However, the objective of the industry is to achieve the optimum results, and as such the results should be considered more analytically, even if the statistical parameters need to be disregarded. The choice of the profiling target can be based on the needs of the user. For applications where a high degree of colorimetric accuracy is required either 'IT8.7/3 Full' or 'IT8.7/4 Visual' should be used. If a reliable profile is required but there are constrains due to space and time, 'IT8.7/3 Basic' could be used instead.

Suggestions for Further Study

The paired comparison tests could be performed with more pictorial images and more judges. In this manner, more consistent judges would remain, after the circular triads verification for inconsistencies, for the evaluation of the results.

The choice of Kodak Approval NX provided excellent reproductions, but a choice of a printer with more variation in its output would allow the evaluation of the profiles under less optimal conditions. The assessment of colorimetric accuracy should also be performed with measurement of printed targets, and not only with the round-trip approach.

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