Quantitative Analysis of ICC Profile Quality for Scanners

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Abstract

ICC profiling software is widely used in the graphic arts industry. The quality of a scanner profile created by profiling software using a single training target is discussed. A more stringent quantitative analysis of the profile quality is proposed. Different targets from different photo paper manufactures are used as the testing targets to compare the quality of the profiles. A grayscale was also used for testing the ability of profiling software to preserve gray balance.

The results show that profiling software can generate apparently high quality profile for the training targets. However, the profile of one target assigned to the scan of other targets, used as originals, does not confirm this accuracy. Additionally, the RMS ΔE values of grayscale assigned profiles are higher than the RMS ΔE values of scanned targets assigned the same profile.

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Introduction

The concept of color management has been incorporated into the printing industry for many years. The typical workflow of reproducing color consists of capturing images by scanners, digital cameras, displaying images on monitors, proofing and printing on press. With the flexibility of digital technology, digitized images are often transformed between input and output devices. Every device has a different color gamut, which affects the quality and color accuracy of the reproduction. The solution is the implementation of a Color Management System (CMS) (Adams, 2001, Sharma, 2004). In closed-loop color reproduction, the color reproduction characteristics of the output device are used to adjust scanner settings, "closing the loop" between input and output devices. In open-system color, a device-independent color space is used as an intermediate step (Adams, 2001, Sharma, 2004). With the device-independent color space, the operators of scanners, printers or presses do not need to know the characteristics of other devices.

A dedicated ICC (International Color Consortium) profile has to be generated for every input and output device, in order to describe their color space behavior. Within the workflow, the Color Management System (CMS) compares the profiles of the data sender, i.e., a scanner, with the profile of the data receiver, i.e., a monitor, and calculates a relation for the conversion, which will translate the image data into the right color impression (LaserSoft Imaging, 2001).

Device profiles provide a color management system with the information necessary to convert color data between native device color spaces and device independent color spaces. Device profiles defined by the ICC specifications store colorimetric information of color imaging devices and can be used to translate color created in one device into another device's native color space. CMMs will receive both image data and source or destination device profiles from the applications or device driver. CMMs firstly use the source profile to convert input image data to an intermediate device independent color space (the Profile Connection Space or PCS), and then use the destination profile to convert intermediate color space to an output device's native color space.

To achieve high image quality throughout a digital imaging system, the first requirement is to ensure the quality of the devices that capture real-world physical images and convert to digital images. Scanners and digital cameras, as the input devices, are now affordable for everybody. As the source of capturing color images in the real world, scanners and digital cameras play an important role in the color reproduction workflow. Without predictable capture and accurate color space rendering, it is impossible to get the correct color display and reproduction, even with a profiled monitor and printer.

Desktop Scanner Calibration and Characterization

Scanners are usually designed for scanning images reproduced on paper or transparencies. In addition, they include their own source of illumination. Color digitizing scanners, which produce RGB output, are important components of desktop color publishing systems. Compared to the high-end scanners, they offer advantages in compactness, low price, and ease of use (Holst, 1998).

The imaging sensor used in most scanners is the CCD, or Charge Coupled Device. A CCD imaging sensor starts at the point of converting light (photons) into electrons. The next step is to read the value (accumulated charge) of each cell in the image. CCD sensors can create high quality, low noise images. Picture quality is strictly related to the number of pixels composing the sensor, the higher the better (Mancuso, 2001). For color accuracy, the most important characteristic of the imaging sensor is its spectral sensitivities. Ideally, they should closely resemble the human visual system's spectral sensitivities (Berns, 2000).

Many color device calibration tasks involve transporting device dependent color, which may be RGB or CMYK, to device independent color space, which may be CIEXYZ (CIE 1931) or CIELAB (CIE 1971). The mathematical model is usually built to correlate the coordinates of device and CIE colorimetry. Scanner calibration refers to adjustment of the response of the scanner's light detectors, so that the detectors consistently record specified digital values for given densities in the original and all detectors record the same digital value (Adams, 2001). With the CCD scanner, it may also mean compensating for any non-uniformity in sensitivity of the individual element of the array (Johnson, 2002).

Scanner characterization provides a way of determining the digital color values output by the scanner in response to specified colors in an original. It defines the relationship between the device dependent color space and the CIE color space. For a scanner, it normally defines the relationship between the voltages quantized as data recorded on the disk and the CIE measurements of the colors scanned (Johnson, 2002). Characterization is affected by such variables as the scanner's dynamic range of densities it can detect, from lightness to darkest; how the scanner renders contrast, as measured by gamma and whether the scanner reproduces neutral colors as neutral (Adams, 2001, Fleming 2004).

Scanner calibration and characterization can be conveniently achieved by using the ANSI IT8.7/2 (ANSI, 1993) as a reflection target. The primary target suppliers are Eastman Kodak, Fuji Film, and Agfa.

Commercial profiling programs are used to compare the raw scanned CIELAB values to the reference value of the target and to create profiles for a certain scanner. The most popular profiling programs are Gretag ProfileMaker, Monaco

Profiler and Fuji ColourKit ProfileMaker. Different software packages usually produce similar results (Sharma, 2003a, b, 2002). Significant differences may occur in using software whose profiles use different color management modules (CMMs). Different scanner profiling software can be evaluated by comparing the ΔE_{ab}^*, ΔH_{ab}^* and ΔC_{ab}^*. A grayscale can also be used to evaluate the color balance (Fleming, 2004).

Experiment and Discussion

The usage of profiling software and standard color targets makes color reproduction easier to be controlled. This research describes the methods that quantitatively evaluate the profile qualities. Desktop scanners used in this research were an HP Scanjet 7400C and a UMAX Astra 4000U. Three targets were Kodak IT8.7/2-1993 1997:08 (specified as Kodak08), Agfa IT8.7/2-1993 1999:03 (C90450XX) (specified as Agfa), and Fuji Film IT8.7/2-1993 2000:05 (specified as Fuji).

Color targets for scanners are supplied by the primary film and photo paper manufacture covered in ISO 12641 (ANSI, 1993). Different targets from different manufactures have different, though similar, CIELAB values. The users usually employ a single target and a single profiling software package. This brings the question to the accuracy of the profile created by one profiling software package using only one target. Here, we present tests of three primary profiling software packages, using three different color targets to find a correlation for different combinations. Commercial profile software packages used were Monaco Profiler 4.5 (specified as Monaco), Gretag ProfileMaker 4.1.5 (specified as Gretag) and FujiFilm ColourKit ProfileMaker 4.04b1.

The experiment was designed as the following parts: the scanner was tested by using a grayscale and IT8.7/2 targets; the quality of profiles were tested by comparing the mean and RMS values of ΔE, ΔL^*, Δa^* and Δb^*. Targets from different manufactures were used as targets to make profiles and as originals to test the profiles. The contour maps of ΔE values were used to display the relationship of different color families and software combinations.

Scanner Testing

A Stouffer® R1215 12 step grayscale (Groff, 1990) was scanned by the HP Scanjet 7400C to test the dynamic range and gray balance. This grayscale proved useful previously for characterization of gray balance along with an IT8.7/2 (Fleming, 2004).

The HP Scanjet 7400C has high dynamic range and good unadjusted gray balance in highlight and midtone areas and only a slight shift in the shadow area of Red, as shown in **Figure 1**.

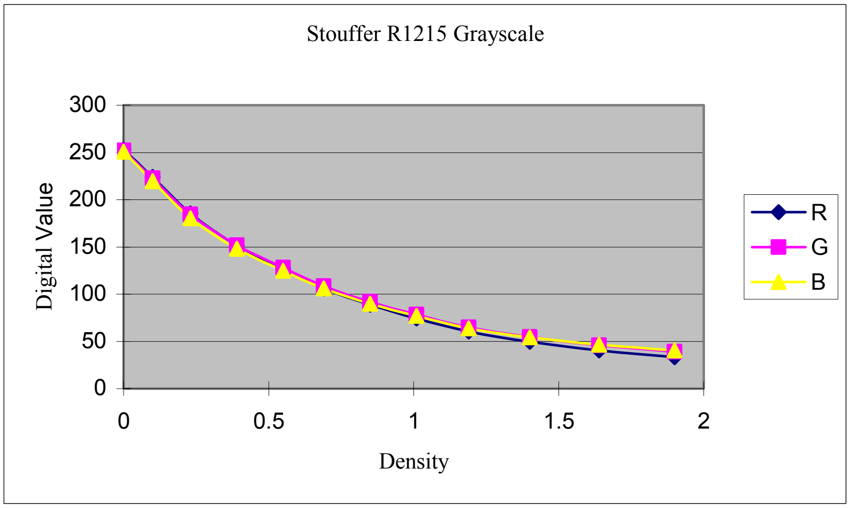

Figure 1: RGB digital values of Stouffer R1215 grayscale scanner by HP Scanjet 7400C with no auto adjustment.

Most of the desktop flatbed scanners have auto exposure and auto color adjustment function. To get the raw digital values of the scanner, all auto adjustment functions have to be turned off (Kress, 2003). Three scans were taken to test the auto exposure function. Tests were set with same scanning area. Test 1 used only the IT8.7/2 target, test 2 used the IT8.7/2 target and Stouffer grayscale, and test 3 used only the Stouffer grayscale. The measured data showed that the RGB values are very close. Thus, when the auto adjustment function is turned off, no adjustments are being made, no matter the size of selected area.

The Accuracy of ΔE Values Provided by Profiling Software

Profiling software Monaco Profiler 4.5 and FujiFilm ColourKit ProfileMaker 4.04b1 (vendors) have the function to display the ΔE values calculated by the software, after every profile is generated. The results are useful to verify our testing procedure. As shown in Table 1, the Monaco values agreed with our test using the method described in Sharma 2002, 2003a, b, while the FujiFilm values did not.

The table suggests that FujiFilm is not calculating the error in the same way as we are. However, Monaco appears to be using a similar methodology to ours. FujiFilm may be using a pre-calculated relationship to predict the error. It would be more useful if they used the populated look-up table in the profile, as that is all that users can utilize.

Scanner profile quality Umax Astra	Agfa IT8.7/2 Chart		FujiFilm IT8.7/2 Chart		Kodak IT8.7/2 Chart	
Mean ΔE	Our	Vendor	Our	Vendor	Our	Vendor
FujiFilm ColourKit* ProfileMaker 4.04b1	1.30B 1.32C	0.81B 0.80C	1.14B 1.03C	0.67B 0.72C	1.02B 1.01C	0.69B 0.75C
Monaco Profiler 4.5	1.14B 1.16C	1.11B 1.14C	0.87B 0.91C	0.81B 0.85C	1.15B 1.16C	1.13B 1.16C

B = profile made with vendor supplied batch measurements
C = profile made with custom made measurements
Table 1: The accuracy of ΔE calculated by profiling software.

The Difference between Measured and Reference CIELAB Values of Three Targets

Every color target has its own reference CIELAB values supplied by the manufacture. However, in our work, the actual CIELAB values were measured by a Gretag Macbeth SpectroScanT in reflection mode, using MeasureTool software. We use these measurements to compare the difference between measured data and reference data. The CIELAB values of scanned images with profiles assigned were read by using our own program (Sharma 2002, 2003a, b).

Table 2 shows the difference between the batch supplied data and data when the chart was measured in our labs. The error contains two components – errors due to batch averaging and errors due to fading of the materials.

Custom vs Batch	*Agfa IT8.7/2 Chart*	*FujiFilm IT8.7/2 Chart*	*Kodak IT8.7/2 Chart*
Mean (Max) ΔE	1.21 (3.31)	3.28 (6.70)	1.88 (6.25)

Table 2 Comparison between custom measured and batch values for three targets.

The reference data for the Kodak targets have the standard deviation included for customer to verify whether the difference is in the tolerance range. According the reference data supplied by Eastman Kodak, the average standard deviation of ΔE on the Kodak 08 is 0.41. This tells us that if the RMS ΔE between measured and reference is equal or smaller than 0.41, the profile created by using the reference data is as reliable that measured using the measured data. The measured and calculated data showed that the mean ΔE between measured and reference Kodak08 is 1.88, which is larger than batch reference value. This relatively small variation might result from the aging effect of the emulsions.

The measurement of three targets indicated that the Agfa target has smaller ΔE values than the other two targets. The FujiFilm has the largest difference. The difference of reference data and measured data will affect the accuracy of the profile when the profile is created by using the reference data of the target.

Profiling Scanner Using Reference Data and Measured Data

In the following parts of this research, the target used to create a profile is called the training target, and the target used to test a profile is called the testing target. Three targets were scanned at the same setting as mentioned in the previous part. In order to compare the consistency of profiling software, two profiles for each target were created by using three profiling programs.

Targets	**Agfa**			**Fuji**			**Kodak08**		
Profiling Software	**Gretag**	**Monaco**	**FujiFilm**	**Gretag**	**Monaco**	**FujiFilm**	**Gretag**	**Monaco**	**FujiFilm**
Mean ΔE	1.13C 1.12B	1.47C 1.36B	1.32C 1.30B	.91C 1.02B	.96C .96B	1.03C 1.14B	1.07C 1.14B	1.25C 1.30B	1.01C 1.02B
RMS ΔE	1.34C 1.37B	2.93C 2.67B	1.85C 1.84B	1.08C 1.11B	1.41C 1.44B	1.28C 1.43B	1.38C 1.48B	2.15C 2.29B	1.23C 1.26B

Table 3: Profiling software consistency test

The RMS ΔE values of the profiles made with the reference data and the measured data are very close to one another (**Table 3**). This confirms that the profiling software packages have consistent profiling ability for using different data to create profiles. In the following tests, profiles were created by using the measured data of color targets, since that gives the best representation of the scanner performance at the time of the experiments.

Obviously, two profiling programs will produce different profiles the same device, even if the differences are negligible for practical purposes. This is illustrated in Tables 4 and 5 for Gretag and Monaco. In addition, ΔL*s, Δa*s and Δb*s can have different contribution to the ΔEs for different packages. Note that the values in Table 4 differ from the corresponding ones in Table 3, because those were calculated from 2 or more scans and measurements. The results in Table 4 represent a single scan and single target measurement with the corresponding profile calculations.

Note that the targets assigned profiles created by Monaco Profiler have higher RMS ΔE and RMS Δa* values. The Δa*s for these profiles are the largest parts of these ΔEs. The extremely large ΔE patches all appeared in the targets assigned with Monaco profiles. Contours of ΔE values of the testing targets, with the assigned profiles created by Monaco Profiler, show the location of the higher ΔE patches (**Figures 2-4)**.

Targets and Profiling Software			ΔE			
Testing Targets	**Profiling Software**	**Training Targets**	**RMS**	**Maximum**	**Average**	**Standard Deviation**
Agfa	Gretag	Agfa	1.42	7.41	1.13	0.87
	Monaco	Agfa	3.73	29.39	1.77	3.28
Fuji	Gretag	Fuji	1.08	7.02	0.84	0.67
	Monaco	Fuji	1.58	11.57	1.00	1.22
Kodak08	Gretag	Kodak	1.5	9.34	1.07	1.05
	Monaco	Kodak	2.58	20.43	1.33	2.21

Table 4: The profile ability of two different profile software —ΔE comparisons.

Targets and Profiling Software			ΔL*	Δa*	Δb*
Testing Targets	**Profiling Software**	**Training Targets**	**RMS**	**RMS**	**RMS**
Agfa	Gretag	Agfa	0.4	0.99	0.94
	Monaco	Agfa	0.54	3.45	1.21
Fuji	Gretag	Fuji	0.35	0.83	0.6
	Monaco	Fuji	0.41	1.36	0.69
Kodak08	Gretag	Kodak	0.46	1.25	0.69
	Monaco	Kodak	0.45	2.31	1.05

Table 5: The profile ability of two different profile software — ΔL, Δa* and Δb* comparisons.

ΔE values of three training targets assigned with profiles created by Gretag ProfileMaker are similarly plotted as contours in **Figure 5**, **6** and **7** to compare with the targets assigned with profiles created by Monaco Profiler. The ΔE distributions are varied.

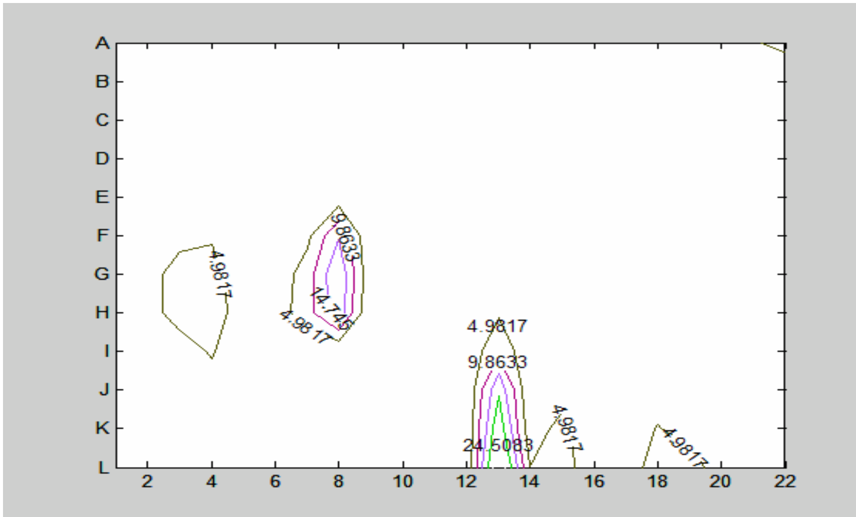

Figure 2: ΔE contour of Agfa target assigned profile created by Monaco Profiler using Agfa as training target (gray scale is excluded).

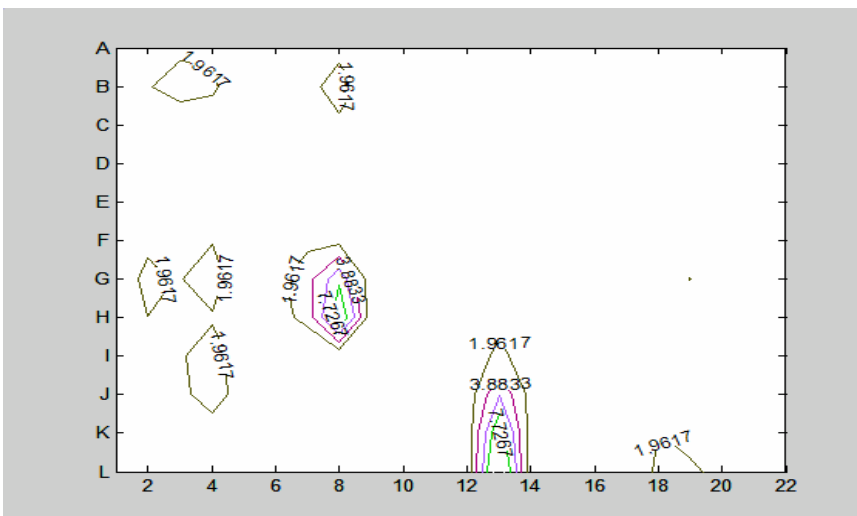

Figure 3: ΔE contour of Fuji target assigned profile created by Monaco Profiler using Fuji as training target (gray scale is excluded).

Unlike the Monaco generated profiles, the highest ΔE values on the three targets assigned profiles created by Gretag do not have the same locations. However, the L16 patches on all three targets, which have the same properties as D_{max} on the grayscale, have higher ΔE values when assigned profiles created by Gretag. This agrees with the ΔE values of D_{max} on the grayscales of the testing targets, where assigned profiles created by Gretag, also have relatively higher values.

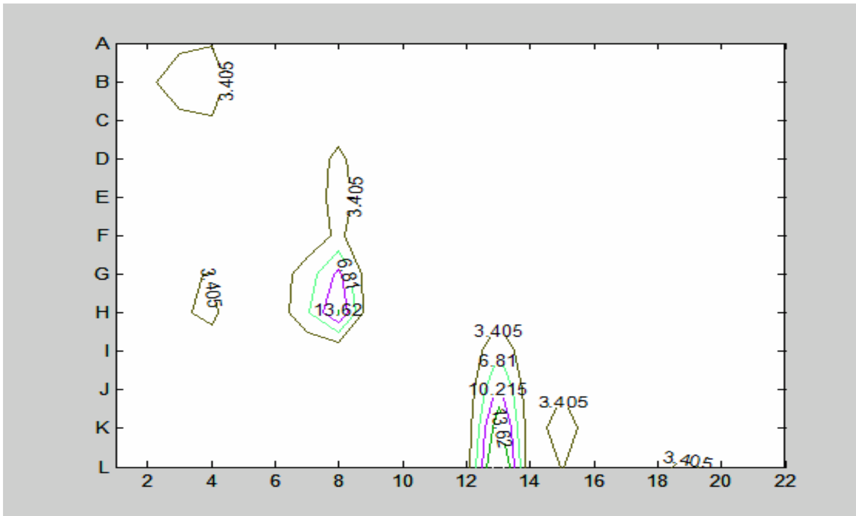

Figure 4: ΔE contour of Kodak08 assigned profile created by Monaco Profiler using Kodak08 as training target (grayscale is excluded).

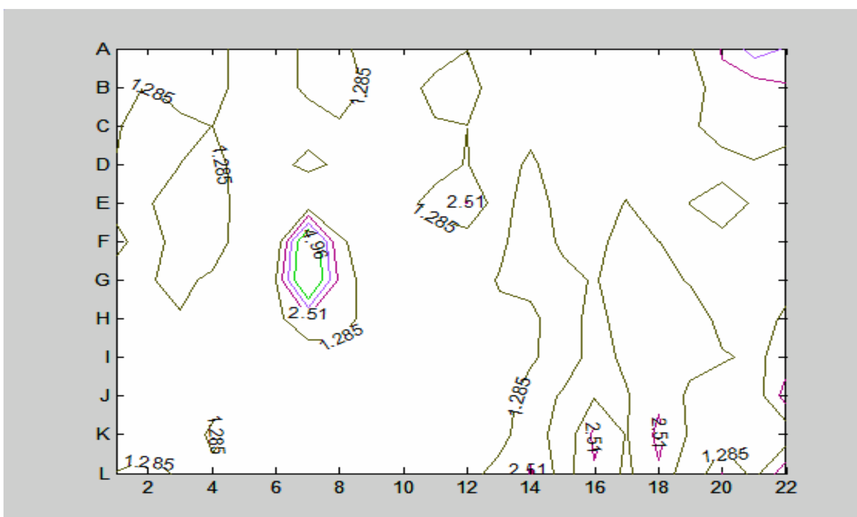

Figure 5: ΔE contour of Agfa assigned profile created by Gretag ProfileMaker using Agfa as training target (grayscale is excluded).

The grayscales on the targets can be used to evaluate the ability of profiling software to process the neutral colors. The importance of grayscale balance in color reproduction was discussed by Fleming 2004.

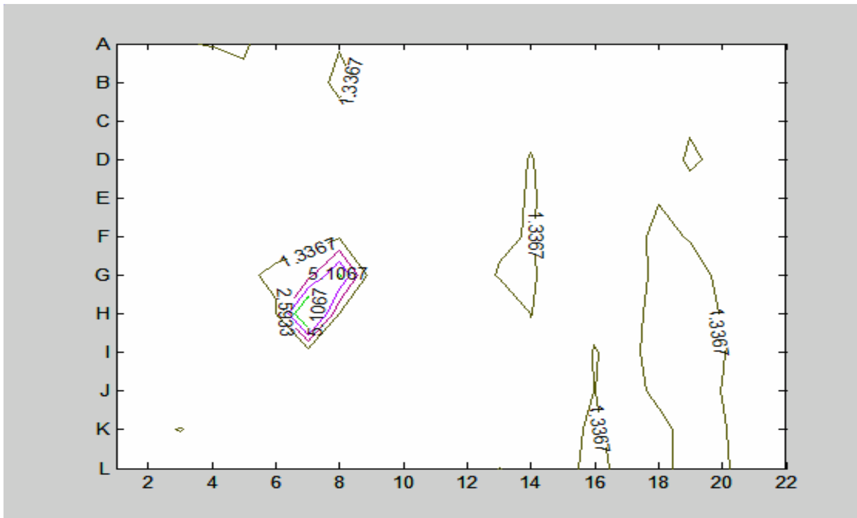

Figure 6: ΔE contour of Fuji target assigned profile created by Gretag ProfileMaker using Fuji as training target (grayscale is excluded)

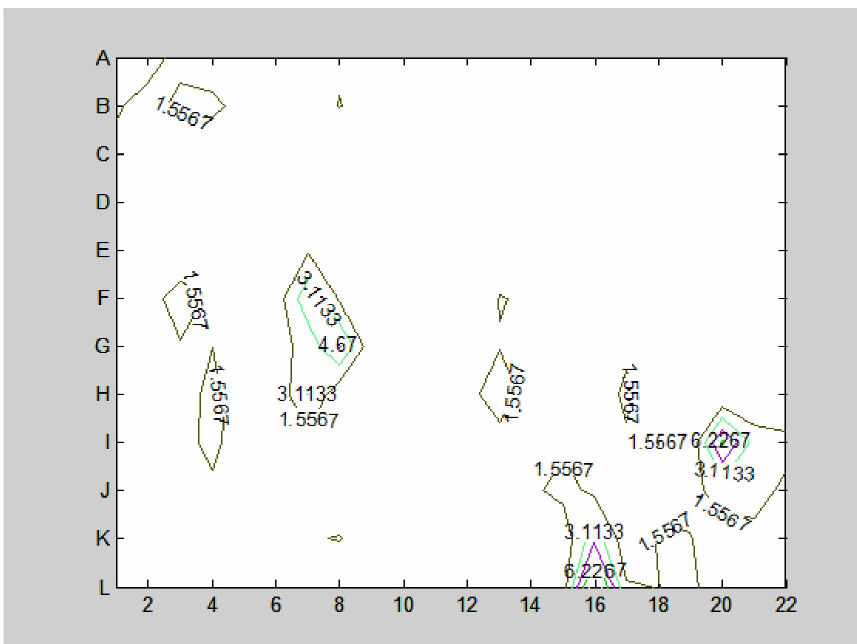

Figure 7: ΔE contour of Kodak08 assigned profile created by Gretag ProfileMaker using Kodak08 as training target (grayscale is excluded).

As shown in **Table 6**, Monaco generated lower RMS ΔE values on the grayscale portion of the targets compared to Gretag, although they are all generally satisfactory. The profiles created by Monaco may be more reliable for reproducing near neutral colors. However, as indicated above, it is less reliable when reproducing some saturated colors.

Targets	Profiling Software	RMS ΔE	RMS ΔL*	RMS Δa*	RMS Δb*
Agfa	Gretag	0.97	0.54	0.41	0.69
	Monaco	0.75	0.35	0.59	0.3
Fuji	Gretag	1.13	0.46	0.91	0.47
	Monaco	0.77	0.33	0.61	0.33
Kodak 08	Gretag	2.47	0.39	2.17	0.72
	Monaco	0.76	0.34	0.64	0.23

Table 6: Δ values of grayscale on training targets

The highest ΔEs on the grayscales from the Gretag profile appeared on the patches with lower or higher densities. The highest ΔEs on the grayscales from the Monaco profile appeared only at higher densities.

This indicates that different profiling software packages have different abilities to identify and process the near gray colors with higher or lower density. It impacts the ability of these profiles to properly reflect the dynamic range of a scanner. The larger ΔE values for D_{max} and adjacent patches for both profiling packages probably reflect the dynamic range of the scanner more than the quality of the profiling process.

Profiles and Targets Cross Testing

In the tests described in of section, six profiles were created by two profiling programs using three targets. By calculating Δ values of three targets assigned profiles created with different targets, we provide a more stringent test of the validity of the profiles. The results showed the different abilities for calibrating and characterizing a scanner with profiling software.

Most profiling software users only make one profile with a single profile target. The originals for color reproduction may vary from one major photo paper manufacture to the other. The profile created by one software package needs to be tested for accuracy, when assigned to an image printed on a different photo paper.

Each of the three targets has two profiles, which were created by the two software packages mentioned above, using measured CIELAB values. Here, the testing targets are assigned profiles other than the one created using themselves to further test the profile accuracy.

In the previous test, Monaco had extremely high ΔE values in the same regions of all three targets. In this part, Gretag profiles also generated high ΔE values, which were over 15 (**Table 7**). Δa*s are slightly higher than ΔL*s and Δb*s. These also follow the tendency of tests in the previous part.

Testing Targets and Profiling Software			**ΔE**				**ΔL***	**Δa***	**Δb***
Testing Targets	**Profiling Software**	**Training Targets**	**RMS**	**Max**	**Average**	**Standard Deviation**	**RMS**	**RMS**	**RMS**
Agfa	Gretag	Fuji	4.76	20.35	3.8	2.88	0.88	3.99	2.54
	Monaco	Fuji	4.27	23.43	3.35	2.65	0.88	3.83	1.68
	Gretag	Kodak08	3.04	9.50	2.64	1.51	0.63	2.55	1.54
	Monaco	Kodak08	3.48	23.78	2.58	2.33	0.54	3.18	1.28
Fuji	Gretag	Agfa	3.99	22.58	3.25	2.32	0.60	3.15	1.81
	Monaco	Agfa	4.15	19.07	3.34	2.46	0.41	3.82	1.56
	Gretag	Kodak08	2.61	14.21	1.97	1.73	0.73	2.28	1.06
	Monaco	Kodak08	2.16	12.1	1.69	1.36	0.50	1.86	0.99
Kodak 08	Gretag	Agfa	3.1	10.2	2.77	1.39	0.46	2.43	1.86
	Monaco	Agfa	4.68	26.35	3.34	3.33	0.51	4.28	1.81
	Gretag	Fuji	3.22	16.02	2.24	2.32	0.8	2.44	1.94
	Monaco	Fuji	3.1	19.98	2.08	2.29	0.83	2.64	1.39

Table 7: Δ values of 3 targets cross testing with different profiles.

The contour maps for the cross testing cases mapped almost the same shapes as the targets assigned profiles created by themselves. This could be explained as, if the profile is created by Gretag using Agfa target, then this profile assigned to Kodak08, the higher ΔEs appear at almost the same places as they appeared in the Agfa Target.

Compared to the Δ values in **Table 6**, the Δ values for the grayscale portion of the targets in **Table 8** are much higher. When the profiles assigned are made from the other targets, the apparent grayscale reproduction appears to be less accurate than expected from the profile made from the target itself. However, profiles created by any profiling software using Kodak08 as the training target have relatively lower ΔE values of the entire targets, and grayscales on the targets.

In this part, profiles created by two profiling programs were assigned to three targets to cross test. The results showed that when the training targets and testing targets are the same, the profiles produce a relatively high measure of apparent profile quality. When the testing targets are different from training targets, the profiling software did not show large differences of profile quality.

Testing Targets and Profiling Software			ΔE	ΔL*	Δa*	Δb*
Testing Targets	**Profiling Software**	**Training Targets**	**RMS**	**RMS**	**RMS**	**RMS**
Agfa	Gretag	Fuji	3.59	0.83	3.22	1.34
	Monaco	Fuji	4.3	0.94	3.86	1.64
	Gretag	Kodak08	2.33	1.15	1.82	0.88
	Monaco	Kodak08	3.06	0.19	2.72	1.38
Fuji	Gretag	Agfa	4.54	1.04	3.85	2.18
	Monaco	Agfa	3.17	0.46	2.77	1.46
	Gretag	Kodak08	4.10	1.84	3.47	1.18
	Monaco	Kodak08	1.30	0.75	0.96	0.47
Kodak08	Gretag	Agfa	3.41	0.62	2.77	1.89
	Monaco	Agfa	2.32	0.66	1.85	1.27
	Gretag	Fuji	1.94	1.08	1.43	0.74
	Monaco	Fuji	2.21	1.12	1.79	0.64

Table 8: Δ values of grayscales on the targets at cross testing.

Additional Profile Accuracy Testing Using R1215 Grayscale

The StoufferR1215 grayscale can also be used to test the accuracy of reproducing neutral colors. The scanned R1215 grayscale was assigned all the profiles that created by Gretag and Monaco profiling software.

Profiles created by any software using Agfa as the training target have relatively lower ΔE values on the R1215 grayscale (**Table 9**). RMS ΔEs and RMS Δb*s are all of the same magnitude. Again, RMS Δa*s are higher. The RMS ΔE values on R1215 are higher than the RMS ΔE values on the targets.

Profiling Software	Gretag ProfileMaker			Monaco Profiler		
Training Targets	Agfa	Fuji	Kodak08	Agfa	Fuji	Kodak08
RMS ΔE	3.70	6.88	5.68	4.40	7.17	6.24
Maximum ΔE	4.61	9.62	6.96	6.14	10.36	8.59
Average ΔE	3.63	6.58	5.61	4.19	6.69	6.01
RMS ΔL*	2.11	2.87	1.86	2.14	2.65	2.16
RMS Δa*	2.62	5.54	4.70	3.45	6.03	5.23
RMS Δb*	1.54	2.90	2.61	1.68	2.84	2.64
Standard Deviation of ΔE	0.75	2.09	0.96	1.40	2.71	1.79

Table 9: Δ values of R1215 grayscale

Assuming that C* of a real neutral gray is zero, ΔC*s (**Table 10**) can be calculated.

Target	Agfa	Fuji	Kodak08	R1215
RMS ΔC*	2.17	3.60	2.56	1.03

Table 10: RMS C* of grayscale on three targets and R1215 grayscale

The RMS ΔC* value of grayscale on the Agfa target is the smallest among the three targets. When the profile created using the Agfa target are assigned to scan of the R1215 grayscale, the RMS ΔE is the smallest as well. Following the same tendency, the profile created by using the Fuji target assigned to R1215 generates the highest RMS ΔE.

Results in this part showed that the way profiling software processes neutral colors on the training targets reflects the quality of profiles in processing real neutral gray colors. Profiles can produce very close CIELAB values of grayscales on targets compared with the measured data. Nevertheless, this profile cannot produce the comparable results when assigned to other grayscales on other targets, which have different CIELAB values and different optical properties.

Profile Accuracy Testing Using Targets from the Same Manufacturer with a Different Manufacturing Date

Different photo paper manufacturers use different photo paper and emulsions, which have different properties to reproduce color. One manufacturer may have more than one color target available. This helps to test the accuracy of profiles when assigned to the targets that are from the same manufacturer but with a different manufacturing date.

Kodak testing targets manufactured at different dates were tested. We have access to Kodak IT8.7/2-1993 1997:08 (specified as Kodak08) and Kodak IT8.7/2-1993 1997:04 (specified as Kodak04). The Δ values are listed in Table 11.

Data show that the profiles created by Monaco Profiler have higher Δ values than those of Gretag ProfileMaker. When cross testing, profiles using Kodak08 have lower Δ values then Kodak04 (**Table 10**).

The RMS Δvalues of grayscale on two testing Kodak targets (**Table 11**) are higher when assigned the profile created by Gretag using themselves as training targets. When cross-testing, Monaco profiles generated higher Δ values.

Cross Testing			ΔE				ΔL*	Δa*	Δb*
Testing Targets	Profiling Software	Training Targets	RMS	Maximum	Average	Std.	RMS	RMS	RMS
Kodak08	Gretag	Kodak08	1.5	9.34	1.07	1.05	0.46	1.25	0.69
	Monaco	Kodak08	2.58	20.43	1.33	2.21	0.45	2.31	1.05
	Gretag	Kodak04	3.6	14.62	2.57	2.53	1.43	2.58	2.06
	Monaco	Kodak04	4.03	19.42	2.77	2.93	1.36	3.13	2.14
Kodak04	Gretag	Kodak04	1.3	5.34	1.05	0.77	0.46	1.02	0.67
	Monaco	Kodak04	2.31	18.98	1.32	1.9	0.54	2.01	1.02
	Gretag	Kodak08	2.49	12.8	1.94	1.57	1.13	1.7	1.44
	Monaco	Kodak08	3.35	19.91	2.27	2.47	1.35	2.68	1.5

Table 11: Δvalues of cross-testing Kodak08 and Kodak04.

Testing Targets and Profiling Software			ΔE	ΔL*	Δa*	Δb*
Testing Targets	Profiling Software	Profile Assigned	RMS	RMS	RMS	RMS
Kodak08	Gretag	Kodak 08	2.47	0.39	2.17	0.72
	Monaco	Kodak 08	0.76	0.34	0.64	0.23
	Gretag	Kodak04	1.94	1.08	1.43	0.74
	Monaco	Kodak04	2.21	1.12	1.79	0.64
Kodak04	Gretag	Kodak04	1.16	0.54	0.93	0.42
	Monaco	Kodak04	1.15	0.59	0.88	0.44
	Gretag	Kodak08	1.9	1.42	0.63	1.10
	Monaco	Kodak08	3.44	2.28	2.11	1.47

Table 12: Δ values of grayscale on two Kodak targets.

The R1215 was used here for evaluating the neutral colors when assigned two different profiles created by using Kodak as the training target. The Δ values (**Table 13**) are very close. It suggests that the two profiles have the same ability to reproduce neutral colors. It also shows that Δ values are higher than data of grayscale on the targets.

The conclusion here is that, when using targets from the same family as the training targets, profiling software can create profiles with similar qualities. When cross testing, the Δvalues are higher, but they are of the same order of magnitude as well. Monaco generated higher ΔEs when cross testing.

Profiling Software	Gretag		Monaco	
Training Targets	Kodak08	Kodak04	Kodak08	Kodak04
RMS ΔE	5.68	5.81	6.24	5.62
Maximum ΔE	6.96	11.16	8.59	6.31
Average ΔE	5.61	5.47	6.01	5.56
RMS ΔL*	1.86	1.71	2.16	0.94
RMS Δa*	4.70	4.24	5.23	4.87
RMS Δb*	2.61	3.58	2.64	2.63
Standard Deviation of ΔE	0.96	2.04	1.79	0.83

Table 13: Δ values of R1215 grayscale assigned profiles created by using Kodak targets.

Further Testing by Using a Different Scanner

The distribution of Δvalues on the targets may vary when the targets are scanned with different scanners. The responses of the CCD sensors are different from one scanner to the other. Thus, the R, G, B values of each patch will be different. When the scanned target is used as the training target, the quality of profiles will be different as well.

The scanner used for further testing was a UMAX Astra 4000U. The Kodak08 and Kodak07 were used as the training targets. The Kodak04 target was scanned at the same setting for comparison. R1215 was used to test the dynamic range and gray balance of the scanner (**Figure 8**).

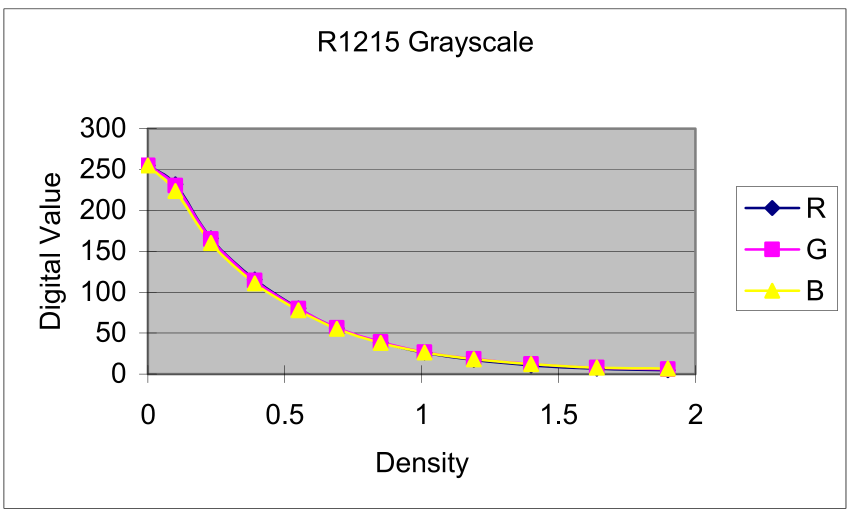

Figure 8: RGB digital values of Stouffer R1215 grayscale scanner by UMAX Astra 4000U with no auto adjustment.

The UMAX Astra 4000U showed a high dynamic range and good gray balance especially in the shadow areas compared with the HP Scanjet 7400C.

Two profiles were created using Monaco and Gretag software with Kodak08 as the training target. The profiles were assigned to the scans of the Kodak08 and Kodak04 targets. The RMS ΔE values are shown in **Table 14**.

Cross Testing			ΔE			
Testing Targets	**Profiling Software**	**Training Targets**	**RMS**	**Maximum**	**Average**	**Standard Deviation**
Kodak 08	Gretag	Kodak08	1.77	4.88	1.42	1.05
	Monaco	Kodak08	1.96	7.64	1.45	1.32
Kodak 04	Gretag	Kodak08	2.12	6.87	1.67	0.81
	Monaco	Kodak08	2.36	7.66	1.75	0.88

Table 14: ΔE values of Kodak08 and Kodak04 assigned profile created by Gretag and Monaco using Kodak08 as the training target.

The RMS ΔE values of the scanned targets assigned with profiles created by Monaco are slightly higher than the profiles created by Gretag. This follows the same tendency of the targets scanned by the HP Scanjet 7400C (**Table 7**). However, the maximum ΔE values are much lower than for the same target scanned by the HP Scanjet 7400C.

RMS ΔL*s, Δa*s and Δb*s (**Table 15**) are very close to one another for both testing targets. The results for the HP Scanjet 7400C have higher RMS Δa* values than RMS ΔL* and RMS Δb* values (**Table 5**).

Cross Testing			ΔL*	Δa*	Δb*
Testing Chart	**Profiling Software**	**Training Targets**	**RMS**	**RMS**	**RMS**
Kodak08	Gretag	Kodak08	1.42	0.58	1.21
	Monaco	Kodak08	0.65	1.28	1.34
Kodak04	Gretag	Kodak08	1.35	1.42	1.32
	Monaco	Kodak08	1.39	1.69	1.59

Table 15: ΔL*, Δa* and Δb* values of scanned Kodak08 and Kodak04 assigned profiles created by Gretag and Monaco using Kodak08 as training target.

The profile created by Monaco is apparently more reliable for reproducing near neutral colors (**Table 16**) according to the data on the targets' grayscale. These results have the same tendency as the results of the HP Scanjet 7400C (**Table 6**).

Testing Targets and Profiling Software			**ΔE**	**ΔL***	**Δa***	**Δb***
Testing Targets	**Profiling Software**	**Training Targets**	**RMS**	**RMS**	**RMS**	**RMS**
Kodak 08	Gretag	Kodak 08	1.99	1.19	1.3	1.19
	Monaco	Kodak 08	0.78	0.35	0.53	0.75
Kodak 04	Gretag	Kodak08	1.58	0.88	0.64	1.06
	Monaco	Kodak08	1.56	0.71	1.06	1.09

Table 16: Δ values of grayscales on Kodak08 and Kodak04 assigned profiles created by Gretag and Monaco using Kodak08 as training target

Higher ΔE values appear at K16, L19 and F3 in **Figure 9**. These patches, which showed the higher ΔE values in Kodak08 target, scanned by the UMAX Astra 4000U, assigned profile created by Gretag profiling software, were seen in **Figure 7** as well. Higher ΔE values appear at L13, K16, L19, H4 and E8 in **Figure 10**, which also appear in the contour map of Kodak08 scanned by HP Scanjet 7400C, assigned the Monaco profile. The higher ΔE values at E3 and E8 in **Figure 4** are also in the Kodak08 scanned by the HP Scanjet 7400C as well.

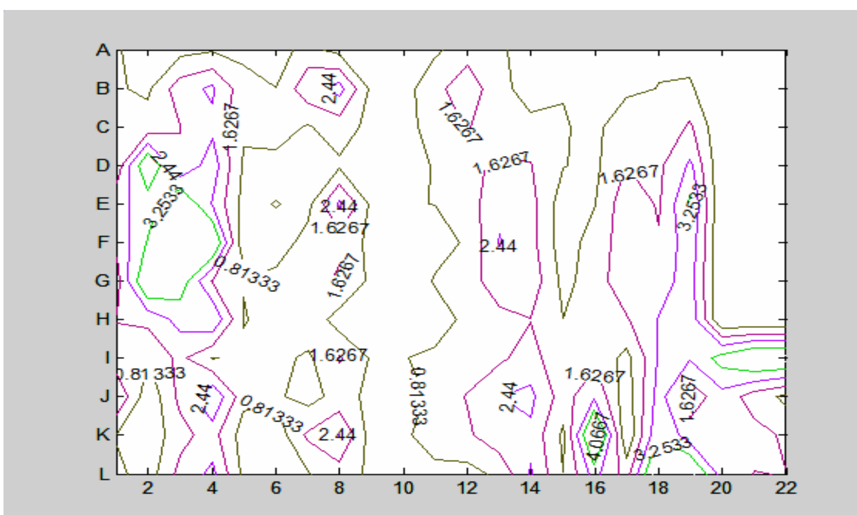

Figure 9: ΔE contour of Kodak08 (scanned by UMAX Astra 4000U) assigned profile created by Gretag ProfileMaker (grayscale is excluded).

The scan of the R1215 was assigned the profiles to test the ability of reproducing neutral colors (**Table 17**).

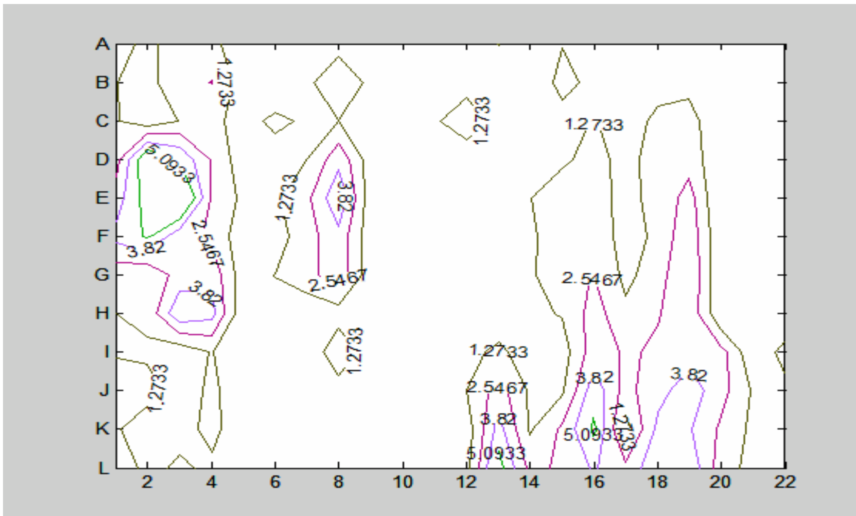

Figure 10: ΔE contour of Kodak08 (scanned by UMAX Astra 4000U) assigned profile created by Monaco Profiler (grayscale is excluded).

Profiling Software	Training Targets	RMS ΔE	Maximum ΔE	Average ΔE	RMS ΔL*	RMS Δa*	RMS Δb*	Standard Deviation
Gretag	Kodak08	7.73	9.89	7.57	2.29	5.06	5.38	1.62
Monaco	Kodak08	8.21	11.21	7.99	1.9	4.8	6.33	2.01

Table 17: Δ values of R1215 grayscale assigned profiles created by Gretag and Monaco.

For the profile created by Monaco assigned to the R1215 grayscale, the Δ values are higher than when assigned the profile created by Gretag. This has the same tendency as the R1215 grayscale scanned by HP Scanjet 7400C (**Table 13**). RMS Δa* and RMS Δb* values are close to one another in **Table 17**.

Similar results also occurred in the cross testing of Kodak08 Kodak07, and Agfa **(Table 18)**.

Scanner profile quality Umax Astra 4000u	**Kodak IT8.7/2 Chart**	**FujiFilm IT8.7/2 Chart**	**Agfa IT8.7/2 Chart**
	Mean (Max) ΔE		
Kodak IT8.7/2 Chart	1.16 (9.15)	1.68 (5.57)	2.41 (13.54)

Table 17: Mean and maximum ΔEs of Kodak08, Kodak07 and Agfa cross testing.

Compared with the results of targets scanned by HP Scanjet 7400C, the results of targets scanned by UMAX Astra 4000U are relative better in terms of RMS ΔE values over the entire targets. RMS Δa* values are smaller for targets scanned by the UMAX Astra 4000U compared to those scanned by HP Scanjet 7400C. This could be related to quality of scanners, which can affect the profile quality.

Conclusions

The experiments described in this research provide methods of quantitative analysis of profile quality. Standard color targets were used to create profiles. Profile quality can be compared by using the color difference-ΔE. For neutral colors, ΔL*, Δa* and Δb* are very useful.

Profiling programs have varying abilities to profile one scanner when using different color targets as training targets. Although the standard of IT8.7/2-1993 describes color patches in chroma hue angle and lightness, every target is manufactured using different photo papers with different emulsions and therefore has different CIELAB values. These differences result in differences in response of the scanner and profiling software.

The accuracy of scanners, especially the special sensitivity of CCD sensors, is also important for profiling software to create accurate profiles.

The profile quality for profiling software that we have examined is generally acceptable (Sharma, 2002, 2003a, b). The differences between different profiling programs are largely how they process the chroma and neutral colors. The RMS ΔE are lowest when the testing target is the same as the training target. When the testing target is different from the training target, the RMS ΔE is about three to four times larger than the RMS ΔE when the training target is also used as the testing target. The RMS ΔE values show that when cross testing, the qualities of profiles do not have large differences. The profile performs better if the training target and testing target are from same family.

The Monaco Profiler usually generates higher ΔE values for highly saturated cyan, blue and some green patches, which have the same chroma or hue angles. The Gretag ProfileMaker always generates higher ΔE values at D_{max} of grayscales. These patches appeared on all the testing targets no matter which targets or scanners were chosen.

For profiling software, L*s are easier to process and a*s have the highest difference. All the testing targets showed that the profiling software can generate low RMS ΔL* values compared to RMS Δa* and RMS Δb* values.

Profiling software can approach CIELAB values of grayscale patches for reference or measured data on any training target. When profiles assigned to the standard grayscale, which is more neutral than the grayscales on the targets, the RMS ΔE is much higher than the RMS ΔEs of the grayscales on the targets. This shows that profiling software has a limited ability to identify and process real neutral colors. RMS ΔEs of neutral grayscales depend on the chromatic values of the training targets. When the training target has lower chromatic values on grayscale, the profile created is better for producing neutral colors. If the grayscale on the target is closer to neutral, the profile created by that target has higher accuracy in reproducing neutral colors.

In conclusion, profiling software needs to be improved in processing real neutral colors and highly saturated colors.

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