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Measuring the quality of ICC profiles and color management software

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1. Introduction

The growth in color management means that there are now many different software packages that can make ICC[1] profiles. But how do we know which is the most accurate and which represents the best value? There is no agreed standard amongst the software vendors and most users are unable to independently assess the quality of profiles. The WMU Profiling Review provides an independent, objective assessment of current software products and ranks them according to their accuracy. In the current version of the review, results of 9 packages to make scanner, printer and monitor profiles are compared. Updates to the WMU Profiling Review occur bi-annually on January 1 and July 1. Any vendor that would like to be included in future revisions is welcome to contact us.

It is important to have a quality measure for ICC profiles because this indicates how well a device has been characterized and therefore how accurate the color is likely to be in a color managed workflow. It is important for software vendors to publish a merit figure and for the industry to agree on how the figure is calculated. Some vendors quote a delta E (ΔE) merit figure and often programs will write out a file with statistics. However there is no indication to tell us how these figures are calculated and whether everybody is measuring the same thing in the same way.

ColorBlind 4.2 displays this dialog after profiling.

The aim of the WMU Profiling Review is to establish some baseline assessment for ICC profiles and thus assist user choice, raise the standard of profiling software and promote the wider acceptance of ICC color management. Car manufacturers publish average fuel consumption (mpg) figures for their vehicles. The ultimate goal of this review is to convince ICC software vendors to do the same.

The assessment of ICC profiles and color reproduction is a complex issue involving everything from color science, psychophysics and image analysis to 'preferred' reproduction styles. The approach adopted in this work is to evaluate the accuracy of profiles using the colorimetric intent. This does not provide an all encompassing result but does provide an indicative set of metric figures that can be used to make valid cross-vendor comparisons.

It is inevitable in a survey of this type that some vendors fared better than others, however this should not be taken as an endorsement of any particular product or manufacturer. Also, whilst colorimetric accuracy is important, the perceptual intent and other features such as visualization tools and profile editing should be considered when making a purchasing decision.

Photoshop 6.0.1, Mac OS 9.2.1 and ColorSync 3.0.4 were used throughout this testing.

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[1] International Color Consortium

2. Scanner profile results (in order)

Scanner profile quality	*Agfa IT8.7/2 Chart*	*FujiFilm IT8.7/2 Chart*	*Kodak IT8.7/2 Chart*	*Final result*	*Price*[1]
	Mean (Max) ΔE	*Mean (Max) ΔE*	*Mean (Max) ΔE*	*Average ΔE*	
Heidelberg					
ScanOpen 4.0.5	0.69 (16.08)	0.63 (2.51)	0.69 (7.53)	0.67	$4,300[2]
ScanOpen 2.1.0[3]	0.99 (15.56)	1.12 (3.28)	0.96 (4.99)	1.02	
GretagMacbeth					
ProfileMaker 4.0	0.85 (2.87)	0.99 (10.13)	1.23 (4.12)	1.02	$3,000
ProfileMaker 3.1[3]	0.85 (2.59)	0.97 (3.21)	1.16 (3.30)	0.99	
Monaco Profiler 4.0	1.19 (9.95)	0.92 (4.70)	1.19 (7.10)	1.10	$4,250
Monaco Profiler 3.2[3]	4.39(15.00)	5.04 (8.25)	4.79 (11.35)	4.74	
FujiFilm ColourKit 2.3	1.15 (3.72)	1.23 (4.53)	1.43 (3.53)	1.27	$3,600
FujiFilm ColourKit 2.2[3]	1.17 (3.98)	1.25 (4.53)	1.42 (3.66)	1.28	
ColorBlind 4.2	1.53 (7.13)	1.95 (8.95)	1.37 (6.92)	1.62	$4,545
ColorSynergy 4.5	2.74 (11.17)	3.05 (10.09)	2.79 (10.43)	2.86	$1,495
Kodak Colorflow 2.2.1	6.86 (36.33)	11.20 (59.27)	6.75 (34.40)	8.27	$2,450
Generic Umax scanner profile[4]	29.80 (44.55)	28.93 (42.03)	29.38 (46.67)	29.37	Free

[1] The price quoted is for a software product (or suite of products) that will make scanner, monitor and printer profiles.

[2] Price includes Sequel Chroma 4 for monitor profiling.

[3] The ranking of the profile and the price is based on the latest release of the software. Older versions of the software are included for reference only.

[4] The generic profile was obtained as part of the Umax scanner driver, Umax VistaScan 3.5.4.

3. Scanner profile discussion

Agfa, FujiFilm and Kodak IT8.7/2 reflection test targets were scanned on a Umax Astra 4000u scanner and profiles were made in the different profiling packages listed.

Tests to measure the accuracy of the scanner profile were conducted as follows. Following profile generation, the raw scan of each IT8.7/2 chart image was opened in Photoshop 6.0.1 with Color Settings> Color Management turned off. Each scanner profile was selected in turn using Image>Mode>Assign Profile and the image was processed to Lab using Image>Mode>Convert to Profile where the Destination Space was chosen as Lab Color. The rendering intent chosen was Absolute Colorimetric and the CMM used was Heidelberg. The Lab value of each patch in the chart image was calculated and a ΔE was computed between this value and the original reference value used in profile generation. A mean and maximum ΔE was calculated over all patches in the IT8.7/2 chart.

The accuracy of each vendor's program is shown in the table. Manufacturers are ranked in order so that Heidelberg ScanOpen provided the best overall result whilst the generic profile was worst. How do we interpret these results? A lower ΔE number is preferable. Profiles with a ΔE less than 2.0 are very accurate scanner profiles. The error in these profiles is so small that it is probably not even noticeable. ColorSynergy (average 2.86) occupied the middle ground and produced a profile that is certainly acceptable. Kodak has an average of 8.27 and should be used in non color-critical work. In color management circles it is often asked how good is the generic profile supplied by the manufacturer? For this scanner the generic profile with a ΔE of nearly 30 was very poor. Note that just because the generic profile is poor, this does not mean that the Umax scanner is poor. In fact the scanner is remarkably good value. In each case the maximum ΔE should also be considered. The best program would ideally have a low mean and a low maximum ΔE.

The scanner profile can contain different look-up tables for different rendering intents - A2B0 (perceptual), A2B1 (colorimetric) and A2B2 (saturation). However this was not always the case. In the early ICC File format specification, scanner profiles used to have only one look-up table, which was called the A2B0 tag. In the 1998 specification, the A2B1 and A2B2 tags for the scanner profile were mentioned but were 'undefined'. In the 2001 revision of the ICC specification (Specification ICC.1:2001-12, Version 4.0.0), the A2B0, A2B1 and A2B2 tags for the scanner profile are explicitly defined. When vendors start to generate scanner profiles that are in complete accordance with the current ICC specification it is likely that some results in this table will change.

4. Printer profile results

Printer profile quality Average ΔE	*HP Designjet 20ps*[1]	*Epson Stylus Pro 5000*[2]
0 – 2		
2 – 4	FujiFilm ColourKit 2.3 GretagMacbeth ProfileMaker 4.0 Monaco Profiler 4.0 Heidelberg PrintOpen 4.0.5	FujiFilm ColourKit 2.3 GretagMacbeth ProfileMaker 4.0 Monaco Profiler 4.0 Heidelberg PrintOpen 4.0.5
4 – 6	Kodak Colorflow 2.2	Kodak Colorflow 2.2
6 – 8	ColorSynergy 4.5	
8 - 10		ColorSynergy 4.5
10 –12		
12 – 14	Generic profile[3]	Generic profile[3]

[1] HP Designjet using the HP RIP v 1.1 SP2 with HP Premium Photo Paper Glossy, batch C6039A

[2] Epson Stylus Pro 5000 using Fiery RIP SPv1.3 in CMYK mode with Epson Photo Paper, batch Y1JL0U744

[3] The HP generic profile was part of the HP driver and was called HPGb2_out. The Epson generic profile was downloaded from www.cgs.de/de/icc.html.

5. Printer profile discussion

Printer profiles contain three rendering intents – perceptual, colorimetric and saturation. Each intent has a forward (Profile Connection Space to Device) and reverse (Device to Profile Connection Space) look-up table. Separate tests were done to evaluate the forward and reverse parts of the absolute colorimetric intent.

For each vendor a CMYK output profile was made in the normal way. The IT8.7/3 chart was used for GretagMacbeth ProfileMaker, Monaco Profiler, ColorSynergy and Heidelberg PrintOpen. Two vendors used a proprietary chart - Fuji ColourKit (FFEI_OUTPUT_CMYK_XY) and Kodak Colorflow (LargeCMYK_DTP41). The GretagMacbeth Spectroscan was used in all programs except for Kodak Colorflow that used the X-Rite DTP41. Default values were used in each program for all settings like black generation and profile quality setting. The profile for each vendor was made and saved.

Next, the basic subset of an IT8.7/3 chart (182 patches) was printed and measured. This provides a set of CMYK values and their measurement in LAB. This is the data that was used to evaluate the forward and reverse parts of the output profile.

This whole process was repeated for HP Designjet 20ps and Epson Stylus Pro 5000 inkjet printers.

To evaluate the forward part of an output profile the LAB values of the IT8.7/3 basic chart were put in an image and using Photoshop the LAB image was converted to CMYK using each profile in turn. The Heidelberg CMM was used and the intent selected in Image>Mode>Convert to Profile was Absolute Colorimetric. The CMYK image was printed and the LAB of each patch was measured. The measured LAB was compared to the LAB that was in the image being sent to the printer. The mean ΔE was calculated and averaged over all the patches. Because of the way the test was conducted all colors sent to the printer were in gamut. The test shows the difference between the particular LAB color you wanted to reproduce and the LAB that you would get if you used that printer profile.

To evaluate the reverse part of the output profile the IT8.7/3 basic CMYK chart was converted to LAB using each profile in turn. We know that when the CMYK patches were printed and measured we got some LAB, if we use the reverse part of each output profile to predict the LAB, then the ΔE between these tells us the error in the reverse part of the profile. To do this the basic (CMYK) chart was opened in Photoshop and converted to LAB using Image>Mode>Assign Profile and then Image>Mode>Convert to Profile (Lab Color). The Heidelberg CMM was used and the intent was Absolute Colorimetric. The LAB of each patch in the digital file was compared to the LAB that was measured earlier. The ΔE was averaged over 182 patches.

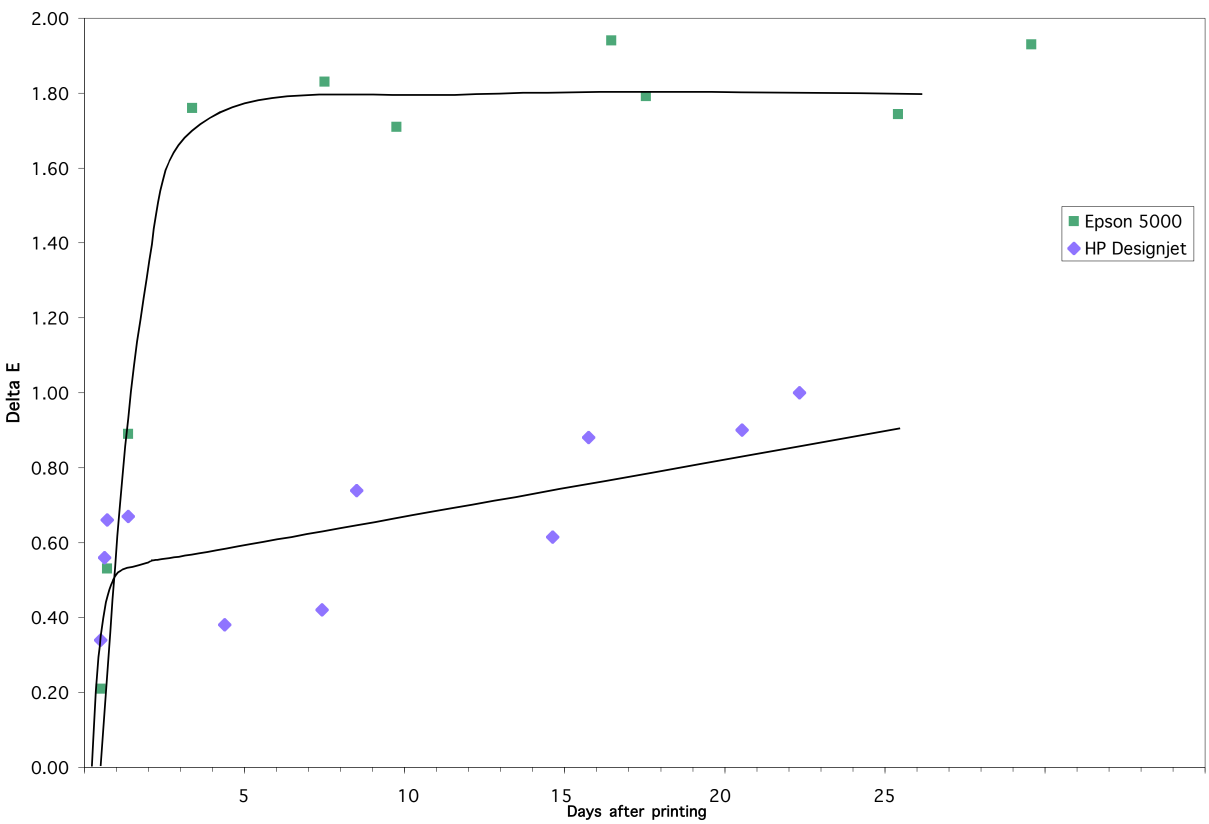
The ΔE for the forward and reverse process was averaged. Due to the instability in the inkjet medium there is uncertainty in the printing and measuring process that was used to derive the results, therefore the data was put into error bands as it is misleading to indicate more precise numbers. To eliminate printer instability, it is possible to do a software only ‘round-trip’ test. This involves taking some in gamut Lab values and converting them to CMYK and then back again to Lab. The ΔE between the start and finish Lab gives us an indication of the accuracy of the profile.

Whilst photographic images are normally processed using the perceptual intent, the colorimetric intent is used during the facsimile reproduction of images, during soft proofing when images are evaluated on a monitor and during proofing when press images are ‘returned’ to the PCS and printed on a proofing device. The colorimetric intent may also be used when legacy CMYK images are opened. So although the colorimetric intent is not normally used to process photographic images it is used in number of very significant ICC workflows and as such is an easily calculated profile accuracy measurement.

It is reassuring to note that in many cases vendors achieve similar results across both printers despite each device having a different RIP and print process. The results produced by the first group of vendors with an average ΔE of 2.0 – 4.0 are very good but keep in mind that a large maximum ΔE could cause problems. The number of grid points used in the profile can also be examined to confirm for example that the forward look-up table has more nodes while the reverse table tends to be more sparsely populated.

6. Inkjet printer stability

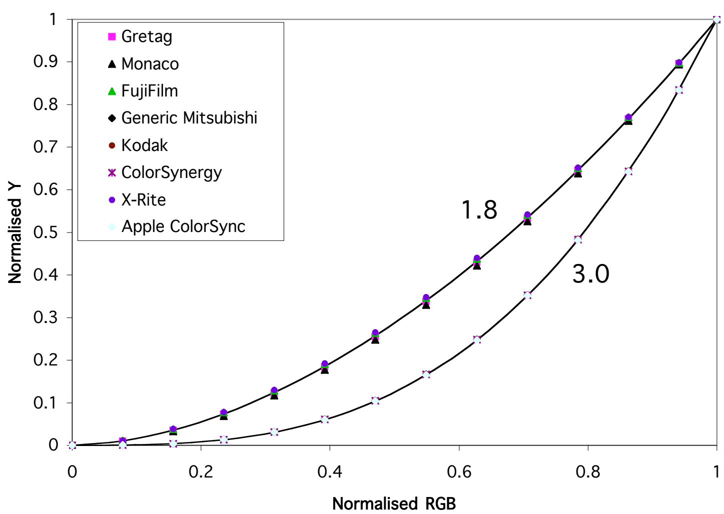
It was necessary in this work to determine the light fastness and color stability of the inkjet images. It was necessary to study how the colors in the image changed with time and therefore make informed decisions on when the test charts should be measured to make a profile and conduct the tests. A full IT8.7/3 chart was printed and left to dry for one hour. It was then measured to provide an Lab reference set. The chart was re-measured over subsequent hours and days and the ΔE was calculated between each measurement and the reference set. It is of interest to the user community to note that the images from the Epson printer change rapidly in the first 24 hours after printing and are not stable for the first 48-72 hours. After that the prints exhibit an average ΔE difference of around 2.0. The HP printer also changed but the changes were always less than 1.0 ΔE. The prints were stored in a windowless office with fluorescent office lighting and typical temperatures of 23°C and relative humidity of 52%. Results for the Epson 5000 are in agreement with published data (R.Work and R T Brown, *Dye and Pigment Ink Jet Image Stability and Permanence*, Proc IS&T NIP17. p414, 2001).



The Epson printer changes color in the first 24-48 hours, whilst the HP printer never changed by more than 1 ΔE.

7. Monitor profile results (in order)

Monitor profile quality	*Measuring instrument*	*Achieved gamma (Target was 1.8)*	*ΔE difference in white point from a target of D_{65}*	*vcgt tag*
GretagMacbeth ProfileMaker 4.0	GretagMacbeth Spectrolino	1.81	0.58	Yes
Monaco Profiler 4.0	GretagMacbeth Spectrolino	1.85	0.68	Yes
FujiFilm ColourKit 2.2	X-Rite DTP92	1.77	3.35	Yes
Mitsubishi monitor generic profile	None	2.99	3.83	No
Kodak Colorflow 2.2.1	None	2.98	3.97	No
ColorSynergy 4.5	Gretag Spectrolino	2.99	4.07	No
X-Rite Colorshop 2.6.2	X-Rite DTP92	1.76	5.81	Yes
ColorSync Monitor Calibrator 3.0.4	Visual	2.03	12.76	Yes



The results are divided into two 'camps'. A perfect gamma of 1.8 and 3.0 are shown by the solid lines.

8. Monitor profile discussion

Eight monitor profiles were tested to see if they were able to achieve a requested gamma and a requested white point. A Mitsubishi Diamond Plus CRT was used on a Power Mac G4. Monitor profiles were made using different measuring instruments as shown in the table and if offered a choice, the user requested a gamma of 1.8 and white point of D_{65}. After each profile was made it was selected as the system profile. Using Photoshop, a series of patches were displayed on the monitor so that the actual white point and actual gamma of the display could be verified.

What happens when you make a monitor profile? Generally you stick a measuring instrument on the face of the monitor and the software displays a series of color patches. This process is measuring the inherent, factory settings of the monitor. The software then asks the user for the setting that they would like. A correction is calculated that converts the factory setting to the user desired setting. Macintosh monitor profiles are distinguished by the use of a 'vcgt' tag that is used to store this correction. Vcgt stands for video card gamma tag and has been part of the MacOS since ColorSync 2.5. What did the results show? In terms of the gamma value, the monitor profiling results fell into two camps. Profiles with a vcgt tag produced a gamma of 1.8 as requested by the user, whilst profiles without a vcgt produced a gamma of around 3.0 which is the inherent gamma of the display. The difference between the color of the profiled monitor and the desired white point of D_{65} was also calculated for each vendor and is shown in the table. The ΔE on a monitor should not be considered as critical as that for a scanner.

9. Issue with Photoshop 6

In this work the Adobe Color Engine (ACE) in Photoshop 6.0.1 was not used due to a problem in the current implementation. In Photoshop 6, when the Image>Mode>Convert to Profile command is used there is the option of selecting the rendering intent. The user is offered the choice of perceptual, colorimetric or saturation intents. *However, for scanner profiles, the ACE CMM always uses the perceptual tag irrespective of the selected rendering intent.* This problem has been corrected in Photoshop 7.

10. About the authors

Abhay Sharma has a BS in Imaging Sciences from the University of Westminster, UK and a PhD in Physics from King's College, London. He worked as a senior research scientist for FujiFilm Electronic Imaging before joining Western Michigan University as an Associate Professor in color imaging. His book *Understanding Color Management* is being published by Delmar Thomson Publishing in 2003. Dr Sharma is a member of the ICC working group that is looking at the issue of profile quality assessment. Paul D Fleming has a PhD from Harvard University. Dr Fleming is Director of the Digital Imaging Research Group at Western Michigan University.

11. WMU Profiling Review -Version history

Version 1.0 Released April 1, 2002. Covered scanner profiles and monitor profiles.

Version 1.1 Released April 9, 2002. Maintenance release to amend one numerical result for Monaco monitor profiling.

Version 2.0 Released July 1, 2002. Scanner profiles - FujiFilm ColourKit updated from 2.2 to 2.3, Heidelberg ScanOpen updated from 2.1.0 to 4.0.5, ColorBlind 4.2 new product included. Where appropriate, data for old and new versions of software is quoted. Printer profiles are new in this release. Printer profiles were made using GretagMacbeth ProfileMaker 4.0, FujiFilm ColourKit 2.3, Monaco Profiler 4.0, Kodak Colorflow 2.2, ColorSynergy 4.5 and Heidelberg PrintOpen 4.0.5. Fading test data is presented for HP Designjet 20ps and Epson Stylus Pro 5000 inkjet printers. Monitor profile data is unchanged from Version 1.1. The product from Color Solutions called basICColor arrived too late to be included in this review. The way the prices are quoted is improved in this version of the review.

12. Publications relating to this review

A Sharma and P D Fleming, 2002 “Evaluating the Quality of Commercial ICC Color Management Software”, Presented at TAGA Annual Technical Conference, North Carolina, April 11-14.

A Sharma, 2002 “A procedure to evaluate the accuracy of ICC profiles”, Circulated by the ICC and discussed as an agenda item at the ICC meeting, Zurich, June 11-14.

A Sharma, M P Gouch, and D N Rughani, 2002 “Generation of an ICC profile from a proprietary style file “, J. Imag. Sci. Tech, 46, 26.

13. Acknowledgements

The author is grateful to James Vogh, Monaco Systems in helping to identify the ACE CMM bug which had an enormous bearing on the scanner results. We are grateful to the following vendors for donating copies of their software and allowing publication of the results – Eastman Kodak, FujiFilm Electronic Imaging, GretagMacbeth, Heidelberg (ScanOpen and PrintOpen), ITEC (ColorBlind), Monaco Systems and Pictographics (ColorSynergy).

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