Using Image Quality Metrics to Evaluate an ICC Printer Profile

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Abstract

The increased interest in color management has resulted in more options for the user to choose between for their color management needs. Evaluating the quality of each of these color management packages is a challenging and time-consuming task. We propose an evaluation using image quality metrics to assess the quality of a printer profile. This will determine the best solution for a given set of objectives. The goal of this work is to create a thorough evaluation for a printer profile to determine the most appropriate profile without using observers.

A printer profile has several aspects that can be evaluated separately: colorimetric accuracy, invertibility, grayscale reproduction, perceptual image quality, smoothness and gamut mapping . In this paper we look for a solution for applying image quality metrics to evaluate the different aspects of ICC printer profiles. The aim of this research is to reduce the amount of time required to compare the overall quality of ICC profiles and give a more thorough evaluation than is typically done by subjectively evaluating each aspect of the printer profile individually.

Introduction

Color management systems are widely used in many industries to transfer color information between devices. The International Color Consortium (ICC) proposes storing transformation data, in the form of Look-Up-Tables (LUT), called profiles. The profiles transform color data between device color and the Profile Connection Space (PCS), an independent color space. The transformation is divided into two parts, one going forward from device color to the PCS (A2B) and an inverse transformation from the PCS to the device (B2A).

The objective of a profile can vary depending on the goal of the reproduction. Many reproduction objectives have been defined [1–3]. Most of these surveys include the following goals: a preferred reproduction, a colorimetrically accurate reproduction, an exact reproduction, and a spectral reproduction. Practically, the ICC specifies four different rendering intents rather than algorithms to address these different goals. The definitions aid the software developers in finding suitable algorithms [4–6]. For this work, we will focus only on the media-relative colorimetric rendering intent.

The main obejctive of the media-relative colorimetric rendering intent is an exact colorimetric copy of the original and not the most pleasing reproduction possible. If the gamut of the destination device is smaller than the source gamut or if the viewing conditions are different, some colors will not be matched. All values from the source that are outside the destination gamut will be clipped or reproduced as defined by the profile creator. It also adjusts for the loss of highlight detail that can result from a destination dynamic range being smaller than the source [7].

Profiles are key to a successful ICC color management system. Printer profiles are evaluated using both psychophysical and metrics methods. Observer based psychophysical evaluations can involve both natural and artificial images that are used to judge the performance of the profile [8, 9]. Profile metric tests for printers often involve calculating the color differences between an original and reproduction of a digital target [10]. Some profile vendors quote a CIE ΔE or calculate some statistics on the quality of a profile that it just generated [11]. An advanced step may include Image Quality (IQ) metrics which return a value that has been adjusted to simulate the human visual system.

The goal of this work is to create a thorough evaluation of a printer profile that determines the most appropriate profile without using observers. We have summarized different quality questions called aspects, to insure a thorough examination of the profile. These aspects are individually evaluated with the IQ metrics and when possible, correlations are drawn with the psychometric tests that we ran to test the different profiles. The metric results are then used to determine an optimal printer profile based on the user's reproductive objectives.

The paper starts with a survey of the existing techniques used to evaluate the different aspects. We then give a brief summary of the IQ metrics used to assess the printer profiles and summarize how they are paired with the aspects. The details of the psychometric tests are discussed next. This is followed by a review of the psychometric tests and metric performance. We finish with the conclusions and future work.

Survey of Profile Evaluation Aspects

The evaluation of a printer profile may be different depending on the user's expectations and the reproduction objectives. For this work we compiled a list of several different quality aspects that consider these different expectations. Aspects that are frequently found in the literature include: colorimetric accuracy [10, 11], perceptual IQ [12] and invertibility [11]. Smoothness [13] and gamut mapping [14] are commonly considered, but not with consumer profile creation software packages [15]. Grayscale reproduction is occasionally mentioned as an important aspect [16]. The aspects are presented in order of importance for the intended objective of the media-relative rendering intent.

Colorimetric Accuracy, (CA): Color accuracy can be expressed by the average color difference between an original and a reproduction under a given viewing condition [10, 11]. The CIE ΔE^*_{ab}, ΔE^*_{94}, and ΔE^*_{00} are all commonly used to quantify the numerical accuracy of an ICC profile. Calculating the mean, minimum, and maximum color differences is a convenient way of comparing the color reproduction abilities of a device and the accuracy of different profiles. This aspect is often tested with a target consisting of in-gamut CIELAB values. This technique restricts the source of any color differences to the profile and/or the color conversion. It is best to evaluate the color accuracy of out of gamut colors separately, to avoid skewing your data. Out of gamut colors may have very large differences that increase the final mean color difference value that gives no indication of the performance of the in gamut colors. Depending on the reproductive objectives, different elements may be used to further assess the mapping technique of these colors, such as the preservation of hue, of lightness, or of saturation.

Invertibility, (INV): Invertibility of an ICC printer profile, evaluates the colorimetric accuracy of the A2B LUT, the CYMK device color to the CIELAB color space [10]. The A2B LUT is relevant for proofing when press documents are transformed back to the PCS and printed on a proofing device. Colorimetric accuracy, when inverting the color transform, is desirable for applications that use the profile in both directions. The 'round trip' test is a useful method to evaluate this aspect [11]. The measurement data used in creating the profile and the original CMYK untagged target are used to find the colorimetric accuracy of the A2B LUT, this tests the LUT's ability to predict the CIELAB values.

Grayscale Reproduction, (GRAY): The grayscale is a measurement tool that evaluates how a system reproduces a series of neutral colors [14]. The reproduction of neutral values is relevant in both black and white and color documents [16]. A document printed with inaccurate gray balance can cause a color cast on the overall document appearance [17]. It is common to evaluate this aspect with a CIE a^*= CIE b^*=0, gradient test target. It is also important to test the accuracy of near neutral hues [16].

Perceptual IQ, (PIQ): The quality of a document can be defined as the impression of its merit or excellence, as perceived by an observer that is not the creator of the document nor closely involved with the subject matter [12]. Having a method of evaluating the perceived quality of the reproduction is essential for assessing the performance of an ICC printer profile. This aspect is often subjectively evaluated using a large collection of images of varying quality. Metrics have been created explicitly to evaluate this aspect,[8, 18].

Smoothness, (SMO): Smoothness is perceived when transitioning between colors. The transition is smooth if it increments in equal color difference steps [15]. Smoothness is a desirable aspect, that is often given a high priority in IQ evaluations [19]. Many studies have evaluated the perceptability of color contouring for both hard and soft copy, and color transforms [20, 21]. Artificial targets such as the Granger Rainbow or other gradients, are used for this test. Two methodologies for creating the gradient targets include: a target consisting of smooth geometrical color variations covering several cross sections and colorimetrically equal steps between two points within the destination gamut. The profile's ability to maintain smoothness is evaluated with both psychophysical and metric evaluations, using both step and smooth targets [15].

Gamut Mapping, (GM): Gamut mapping is the transformation of colors from an original to a reproduction. Different algorithms used to map colors between gamuts of different sizes are often evaluated by comparing them to each other [3]. Vectors that map the colors between gamuts can be used as a visual tool to assess the mapping performance. The user can visualize how the color information will be treated differently. This aspect, for our work, evaluates how the vendor has mapped out of gamut colors with emphasize on how well the relationship is maintained between pixels of similar values.

IQ Metrics

The IQ metrics are summarized here with a brief description and their intended use. We also describe how we use the metric, for which aspect, and if any additional steps were taken with the output. The selection of metrics was based on the original intended use, the goal of our evaluations, the popularity and the authors' prior knowledge of the metrics. A summary of the aspect and metric pairs can be found in Table 1.

CIE LCH, ($\Delta L^*_{\mathrm{STDV}}$): statistics on lightness, hue and chroma were used to assess the gamut mapping aspect. The lightness difference vectors from the detail accuracy targets were used to assess the gamut mapping aspect. The standard deviation of each target was returned as the final metric value.

S-CIELAB [22]: a spatial color difference metric that extends the CIE ΔE^* with a spatial filtering that simulates the human visual system, used here to assess color accuracy

profileQA [23]: is a script used to evaluate the colorimetric accuracy of a profile (software only). The same statistics were calculated for the B2A1 and A2B1 LUTs separately. The A2B1 LUT results were used to assess the invertibility of the profile.

Busyness, (Busy_{L^*}) [18]: with a Sobel filter and some morphology functions this metric was created to detect the details in a scene to find images with similar content. This metric was used to asses the GRAY aspect, lightness channel only. The tolerance threshold was modified to better assess our documents. We used the absolute difference between the original and the reproduced document as the final metric value, since we are evaluating the media-relative intent.

Structural Similarity, (SSIM) [24]: uses a combination of luminance and contrast algorithms to compare the local and global structural information between two images. It is used here to assess the detail accuracy of complex documents and contrast preference.

2nd Derivative, (2ndD) [15]: used to evaluate the smoothness of color transforms. First the color differences between consecutive points within a uniformly spaced gradient are calculated, the derivative of this vector is then computed. It is used here to assess the smoothness aspect, by summing the number of occurrences that the derivatives exceeded a threshold. The threshold is set to the color difference used to create the targets.

Psychometric Setup

The metrics described above were evaluated by asking 15 observers to scale a set of documents in five different psychometric tests. For each test, the observer was asked to rank the document based on a specific attribute. The five tests went as follows: overall preference, smoothness, colorimetric accuracy, detail accuracy, and contrast preference. With the exception of the smoothness test, a digital 'original' was displayed as a reference. All of the tests were carried out in a laboratory environment designed to follow the CIE guidelines [25].

Document Suites

Each psychometric test had a unique document suite of varying content. The documents consisted of both natural and com-

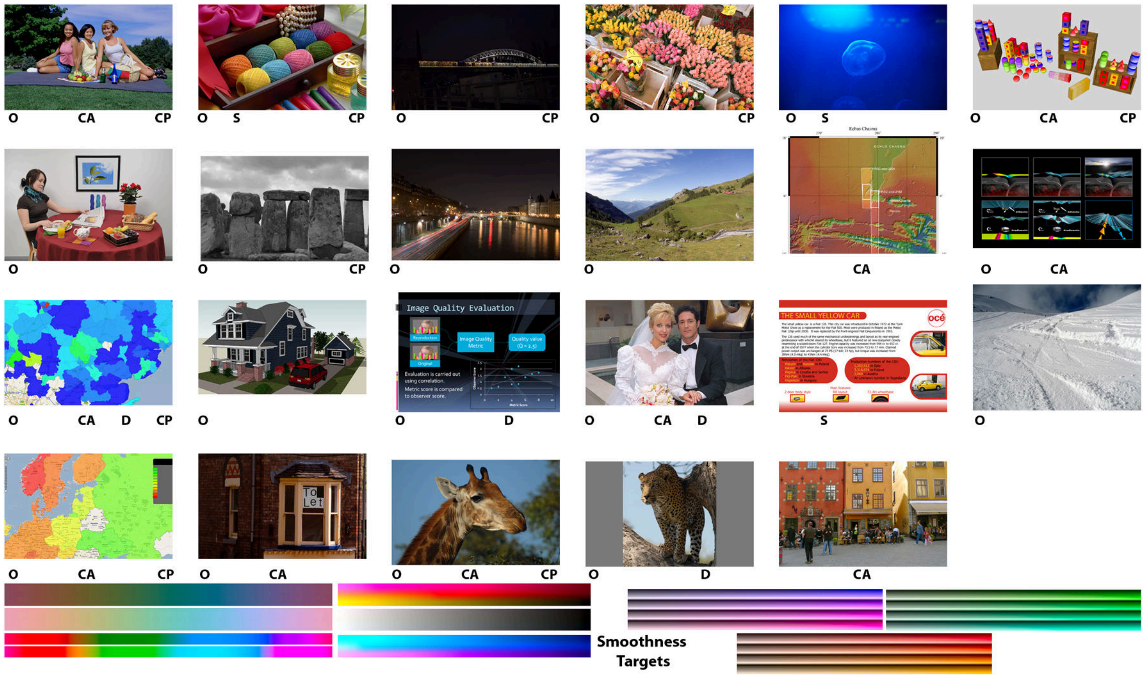


Figure 1. All documents used in the psychometric evaluation. Please note the letters directly below the images, they represent which test(s) each document was used in. Overall(O), Smoothness(S), Color Accuracy(CA), Detail Accuracy(D), and Contrast Preference(CP). The smoothness test targets are at the bottom.

puter generated images, to address the Océ customer. A thumbnail example of the documents can be found in Figure 1 and a summary of the metrics, corresponding aspects and document suites are listed in Table 1. The overall and contrast preference suites consisted of 20 and 10 complex documents respectively. The other suites are explained below.

Smoothness: 12 documents, three complex documents with clear gradients and nine targets generated in Matlab. All test targets were created in the CIELAB color space and increased in one dimension while keeping the other dimensions constant. The CIE Δ_{94} color differences between consecutive steps were the same for all steps within each target. The targets went as follows: three lightness targets set at different hue and chroma values, two targets increasing in hue angle with set lightness and chroma values, one target had three chroma gradients that crossed the a*=b*=0 axis, and three targets that increased in chroma set at different hue and lightness values.

Color Accuracy: included 10 complex documents. All documents had a region of the document in focus while the rest was out of focus, for both the print and the display. The observers were asked to make their judgments based only on the region in focus. This was done to separate in and out of gamut colors. Five document regions were in gamut and five were out.

Detail Accuracy: consisted of eight documents, four complex and four targets. The complex documents all had regions of fine detail. The four targets were composed of hue ramp gradients, two were in and two were out of gamut. The center of each target was one CIELAB L* unit less than the neighboring pixels. For the targets, the observers were asked to judge the prints based on how well the line was maintained through the center.

Table 1: Aspect, metric and document suite pairings are listed along with the number of documents used for each aspect. The type of document is listed in the last column.

Aspect	Metric	Document Suite	# Docs	Complex / Targets
CA	S-CIELAB	Color Accuracy	10	10/0
INV	profileQA	Color Patches	1	0/1
GRAY	$Busy_{L^*}$	Black and White	6	1/5
PIQ	SSIM	Detail Complex	4	4/0
PIQ	SSIM	Contrast	10	10/0
SMO	2ndD	Smooth Target	9	0/9
GM	ΔL^*_{STDV}	Detail Target	4	0/4

Printing

Three ICC v2 printer profiles were created. CMYK percentage reference files were printed through the Onyx Production-House RIP-Queue x10 and measured with an X-Rite eye-one iO using GretagMacbeth's ProfileMaker 5.0.8 Professional Measure Tool. All testing used MathWorks MATLAB R2007a and Adobe Photoshop CS5. All of the documents were printed with a Canon image PROGRAF iPF700 CMYK printer on Océ premium coated matte paper (IJM113). The profiles were applied in Onyx's Preflight application with 16 bit image processing and media-relative rendering intent set and no black point compensation.

Psychometric Details

For the overall preference, color accuracy, detail accuracy and contrast tests, the reference document was displayed on an EIZO ColorEdge CG221 display (with flare hood) at a color temperature of 5000K and a room temperature of approximately

5200K. The display and three prints were viewed simultaneously, with the display to the left of the prints, both approximately 24 inches from the observer. The documents were presented using the digram balanced latin square, to assure a unique viewing order for each observer [26]. All 15 observers passed the Ishihara color blindness test. Five observers were considered experts.

The instructions were specific for each of the five tests. When the display was involved they were asked to look only at the start of each document and avoid looking back and forth. The instructions were read out-loud and a printed copy was available for reference, both in English. The instructions, generally went as follows: scale the accuracy or your preference of each document, using a 1 to 5 scale. 1 is the most: preferred, smooth or accurate, 5 is the least and 3 is neutral. The prints can be ranked the same.

Experiment Results

Two sets of results are discussed, the five visual tests and the metric performance. The method used to validate the metric performance is explained and the correlation results are summarized. The metric results for each aspect are reviewed and finally the performance of each profile is assessed using the IQ metrics.

Psychometric Results

The z-score results of the psychometric tests are summarized in Figure 2. Profile 2 was significantly preferred over the other profiles for all tests but smoothness. Profile 3 was preferred over profile 1 for all tests and significantly preferred for all but the two preference tests (overall and contrast). The observers strongly disliked the smoothness, color accuracy and detail accuracy of profile 1. It should be noted that the PCS colorspace for profile 1 is different than the other profiles, it uses CIE *XYZ*. There were some visible artifacts with the out of gamut target prints from profile 1 that may have been caused by the different PCS.

For each psychometric test, the error bars in Figure 2 indicate 95% confidence interval, $\pm 1.96 \times \frac{\sigma}{\sqrt{n}}$, where n represents the product of observations and documents for each test.

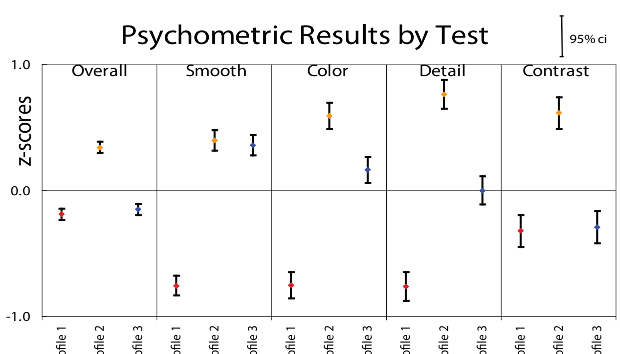


Figure 2. *Psychometric evaluation z-score results for all observers with 95% confidence intervals, listed by test.*

Correlation Technique

As mentioned, IQ metrics usually return one number, often a mean of the error map that the metric generated, but not all return a single number. When necessary an additional step was taken to find a single number to describe the result of the metric. Once each document for each aspect had a single number describing the result of the metric, the performance could be assessed by analyzing the correlation of the metric results to the observer studies, when the observer data was available. The investigation reviewed the metrics on a per document and overall basis.

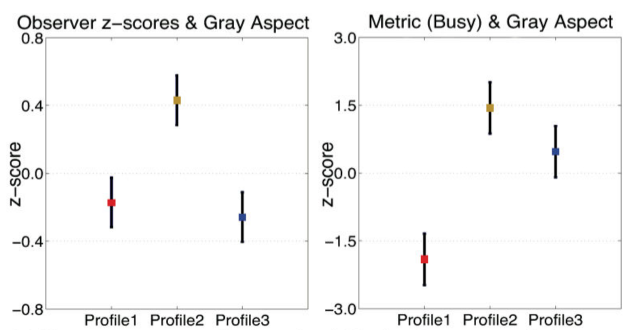
Pearson's correlation coefficient, $\rho_{X,Y} = \frac{Cov(X,Y)}{\sigma_X \times \sigma_Y}$, was used to describe the relationship between the metric and visual results, per document. The coefficient indicates the linear relationship between two variables on a scale of +/- 1, the closer the values are to +1 the better the correlation was between the metric and visual results.

For each document, the metric values and the z-scores of the observer results were used to find the correlation. The mean of these correlations, for each aspect, are reported. The percentage of correlations above 0.6 is also listed to give an indication of how many documents have a higher than average correlation.

Another technique used to evaluate the performance of the metrics is the rank order correlation [27]. The metric results of all the documents are ranked and used to obtain z-scores. These are compared to the z-scores of the observers, and the correlation between them are used as a measure of performance. Together with the correlation values we report the p-values and perform a visual assessment of the z-scores to validate the correlation. Additionally, we indicate (based on the z-scores), if the metric and observer results report the same 'best' profile.

Metric Results

The correlation results are summarized in Table 2. Included in the table is a yes/no column, indicating whether or not the metric chose the same 'best' profile as the visual data, this result is taken from the z-scores compared in the rank order correlation, illustrated in Figure 3. In the example, both metric and observer preferred the same profile, profile 2. A second criteria in the table indicates whether the preference was significant. In the example the confidence intervals, yielded by the metric, overlap with profile 2 and profile 3, so the preference is not significant.



(a) Observer z-scores, used in the rank order correlation for the GRAY aspect.

(b) Rank order z-scores with the Busyness metric for the GRAY aspect.

Figure 3. *The two sets of z-scores were used to calculate the rank order correlation in Table 2, for the GRAY aspect. Both metric and observer results chose profile 2 as the preferred profile for this aspect. However, profile 2 and 3 are overlapping for the metric results, so the preference is not significant. In Table 2, this result would be reported as Yes(No). This plot visual confirmation was performed for all correlation results.*

CA - The mean correlation was very high for this aspect, 0.85 and 90% of the documents showed a correlation of 0.6 or higher. The one document with a low correlation still had the documents ranked in the same order. The rank order correlation

Table 2: Performance of the IQ metrics used to assess each aspect. The mean correlation uses Pearson's coefficient per document and the average is reported, along with the percentage of correlations above 0.6. The rank order correlation is between *z*-scores of the ranked metric data and of the observer results, the *p*-values of the rank order correlation are also listed. The final column indicates whether or not the metric picked the best profile and if it was picked with 95% confidence.

Aspect	Metric	# Docs	Mean Correlation	Above 0.6	Rank order		
					Correlation	*p*-value	Yes/No
CA	S-CIELAB	10	0.85	90%	1.00	0.01	Yes(No)
INV	profileQA	1	n/a	n/a	n/a	n/a	n/a
GRAY	Busy_{L^*}	6	0.38	67%	0.64	0.56	Yes(No)
PIQ $_{\text{Detail}}$	SSIM	4	0.92	100%	0.99	0.08	Yes(Yes)
PIQ $_{\text{Contrast}}$	SSIM	10	0.72	80%	1.00	0.10	Yes(Yes)
SMO	$\text{2ndD}_{\text{Target}}$	9	0.73	89%	1.00	0.02	Yes(No)
GM	ΔL^*_{STDV}	4	0.94	100%	0.87	0.32	Yes(Yes)

was an exact match to the visual data.

With our evaluation, the correlation and the profile performance was not affected by the documents being in or out of gamut. The ranking between the profiles (for both metric and visual tests) remained the same for all documents, with only one exception, profile 3 had a higher color accuracy for a document that was out of gamut. Several commonly used color difference metrics were considered for this aspect.

INV - Correlation statistics were not calculated for this aspect. The profileQA metric reports the mean, standard deviation, and maximum color difference for a 'round-trip' test on the 625 color patches. Ideally, a printer profile will have as small of a color difference value as possible. For our test, the mean color difference returned indicated that profile 3 had a slightly lower color difference on average than profile 2. Profile 1 had a very large average color difference, for this software only metric.

GRAY - Using only the lightness channel, the busyness metric correlated with mixed results. 67% of the documents had a correlation of 0.6 or higher. The challenge for finding a metric with a high correlation with this aspect, was that the documents crossed between different visual tests. A larger document set may have improved these results. The chroma channel was also evaluated, to determine if the reproductions added color information to the black and white documents. This variation of the metric also returned mixed results.

PIQ (Detail and Contrast) - The objective for this work was to find a single metric value for each aspect. PIQ is a large aspect with many quality attributes to consider. For this aspect, we have used one metric and two corresponding visual tests. Between the metrics we tested, SSIM had the highest correlation with both detail accuracy and contrast preference. Comparing the detail accuracy visual test to SSIM resulted in a strong mean correlation of 0.92 and all correlations were higher than 0.6. However, one should consider that only four documents were used in this assessment. The contrast preference also resulted in a good correlation, 0.72. With detail and contrast, the ranked order z-scores correlated perfectly with the observer z-scores both in terms of correlation and visual inspection.

SMO - The 2ndD metric had a strong correlation with the observer results, 0.73 and 89% were higher than 0.6. The ranked metric results and observer z-scores correlated completely. The preference of profile 3 over profile 2 was slight but consistent with both metric and visual tests. Interestingly, when the complex documents and targets were both included, the rankings between metric and observer results still agreed and the rank changed between profile 2 and profile 3. Although the creator of the metric did not use complex documents, it may be extended to include them, by cropping the area of interest.

GM - The standard deviation of the lightness differences yielded a good correlation, 0.94 and all four targets had a correlation above 0.6. The targets created for this assessment were a good tool, especially for out of gamut colors. For future testing, additional targets could be made that have different chroma and separately different hue values, the standard deviation could be used on these difference vectors.

Profiles Compared

A summary of the profiles' performance is illustrated by their metric results in Figure 4. Profile 2 outperformed the other profiles in both accuracy and preference, the exceptions were smoothness and invertibility. If the profile was created for a soft-proofing workflow, profile 3 may be a better option than profile 2 because of the invertibability aspect. Profile 1 performed the poorest with all tests but contrast where the results were close between the profiles. Observers had the most variation with the contrast preference. The correlation results confirmed the metric findings. The main objective of the media-relative rendering intent is a close colorimetric match between the original and reproduction, and not the most pleasing reproduction possible. Due to this, when reviewing the results colorimetric accuracy should be weighted more heavily than the other aspects.

Conclusion

In this paper, we have surveyed a number of profile evaluation methods and assembled a list of the key performance aspects of a printer profile. We found a metric to assess each of the aspects to enable a user to have a robust solution for evaluating profiles to reduce the dependency on human observers. Visual experiments with both expert and naive observers was carried out and acted as a validation to the IQ metrics chosen.

In the future, we aim to expand the assessment to include other rendering intents. In the case of perceptual rendering intent, the complexity will increase for a high correlation is more difficult to achieve when comparing preference over accuracy.

References

[1] J. A. C. Yule. *Principles of Color Reproduction - Applied to Photomechanical Reproduction, Color Photography, and*

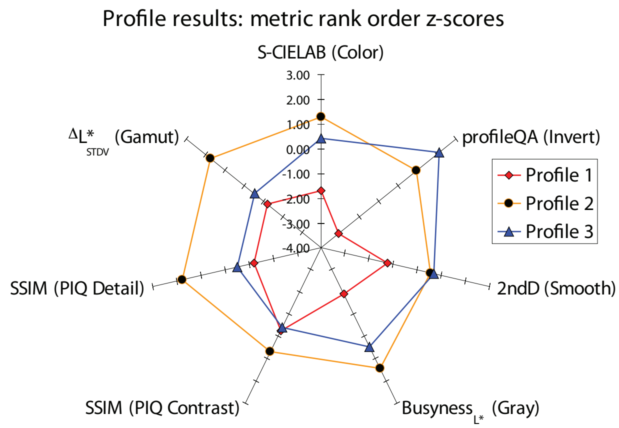


Figure 4. *The three profile rank order z-scores, used for the rank order correlation, are plotted against each other, by aspect. Profile 2 performed the best with the largest shape and a larger z-score for all aspects but smoothness and invertability.*

the Ink, Paper and Other Related Industries. John Wiley and Sons, Inc., 1967.

[2] R. W. G. Hunt. *The reproduction of colour*. Wiley, sixth edition, 2004.

[3] Ján Morovič. *To Develop a Universal Gamut Mapping Algorithm*. PhD thesis, University of Derby, 1998.

[4] ICC.1:2004-10. Image technology colour management - architecture, profile format, and data structure, 2004.

[5] International Color Consortium. ICC White Paper 1: Fundamentals of the Version 4 Perceptual Rendering Intent. 23/03/10: www.color.org, Dec 2004.

[6] International Color Consortium. ICC White Paper 9: Common Color Management Workflows and Rendering Intent Usage. 23/03/10: www.color.org, Mar 2005.

[7] International Color Consortium. ICC White Paper 40: Black-Point Compensation: Theory and Application. 23/03/10: www.color.org.

[8] H. Bring, P. G. Herzog, and Eggert Jung. Evaluation of current color management tools: Image quality assessments. In *CGIV 2004: The Second European Conference on Colour Graphics, Imaging and Vision*, pages 459–462, Aachen, Germany, Apr 2004. CGIV.

[9] P. Rao, M. R. Rosen, and R. S. Berns. Performance evaluation of profile maker professional 5.0 ICC profiling software. Technical report, Rochester Institute of Technology, Rochester, New York, United States, Jan 2005.

[10] A. Sharma. Methodology for evaluating the quality of ICC profiles – scanner, monitor, and printer. *Journal of Imaging Science and Technology*, pages 469–480, 2006.

[11] A. Sharma. Measuring the quality of ICC profiles and color management software. *Seybold Report 4*, 20:10–16, 2005.

[12] B. W. Keelan. *Handbook of Image Quality: Characterization and Prediction*. Marcel Dekker, New York, 2002.

[13] P. Green. *Color Management: Understanding and Using ICC Profiles*. Wiley-IS&T Series in Imaging Science & Technology, Feb 2010.

[14] E. J. Giorgianni and T. E. Madden. *Digital Color Management: Encoding Solutions*. John Wiley and Sons, Inc., 2009.

[15] Phil Green. A smoothness metric for colour transforms. In *Color Imaging XIII: Processing, Hardcopy, and Applications*. SPIE-IS&T, 2008.

[16] Huanzhao Zeng. Neutral gray adjustment in printer ICC profiles. In *Color Imaging VIII: Processing, Hardcopy, and Applications*, volume 5008, pages 341–348. SPIE, 2003.

[17] E. Enoksson. Digital test form for ICC-profiles. In *TAGA Conference Proceedings*, pages 454–473, Vancouver, Canada, Mar 2006.

[18] M. Orfanidou, S. Triantaphillidou, and E. Allen. Predicting image quality using a modular image difference model. In Susan P. Farnand and Frans Gaykema, editors, *Image Quality and System Performance V*, volume 6808, page 68080F, San Jose, CA, USA, Jan 2008. SPIE.

[19] Siv Lindberg and Phil J. Green. Methods of quality assessment for large sample sets. *Journal of Imaging Science and Technology*, 49:442–449, 2005.

[20] Y. Bang, Z. Pizlo, and J. P. Allebach. Discrimination based banding assessment. In *NIP19: International Conference on Digital Printing Technologies*, pages 745–750, New Orleans, LA, Sep 2003.

[21] P. Zolliker and K. Simon. Continuity of gamut mapping algorithms. *Journal of Imaging Science and Technology*, 15:220–233, 2006.

[22] Z. Wang and J. Y. Hardeberg. An adaptive bilateral filter for predicting color image difference. In *17th Color Imaging Conference*, pages 27–31, Albuquerque, NM, Nov 2009.

[23] H. Boll. Matlab script: ProfileQA. 23/03/10: http://www.mathworks.com/matlabcentral/fileexchange/3674-profileqa, July 2003.

[24] Z. Wang, A. C. Bovik, H. R. Sheikh, and E. P. Simoncelli. Image quality assessment: from error visibility to structural similarity. *IEEE Transactions on Image Processing*, 13(4):600–612, 2004.

[25] J. Morovic and M. R. Luo. The fundamentals of gamut mapping: A survey. *Journal of Imaging Science and Technology*, 45:283–290, 2001.

[26] G. Keppel and T Wickens. *Design and Analysis. A Researcher's Handbook*. Pearson education, Upper Saddle River, New Jersey, USA, 2004.

[27] M. Pedersen and J. Y. Hardeberg. Rank order and image difference metrics. In *CGIV 2008 Fourth European Conference on Color in Graphics, Imaging and Vision*, pages 120–125, Terrassa, Spain, Jun 2008. IS&T.

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