Matching Printed Color Images under the Influence of OBA Using a Soft Proofing System

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Keywords: color management, OBA, soft proofing, psychometric

Abstract

Soft proofing is a solution for print buyers and printers who want to decrease production cost and cycle time. When print buyers are increasingly specifying brightened papers, the use of the standard printer ICC profile, e.g., SWOP 3 and GRACoL 2006, as the source color space in the ICC-based color proofing workflow, no longer suffice. This is because the proof looks yellowish in comparison to the brightened print with a bluish white point that print buyers desire. To overcome the mismatch between the soft proof and the brightened print, this research builds a number of source ICC profiles, including profiles built using the substrate-corrected colorimetric aims (SCCA), and profiles built using full dataset. By conducting psychometric tests in a soft proofing environment, the results indicate that (1) the soft proof to brightened print match depends on the source ICC profile; (2) source ICC profiles, built from a fully characterized dataset or the substrate-corrected dataset, improve color match between the soft proof and the brightened print; and (3) the degree of color match between the soft proof and the print is image-dependent.

Introduction

Commercial printing papers historically do not contain OBA. Standard proofing stocks do not contain OBA either. The UV output of a typical viewing light source is of no concern because there is no color difference caused by OBA excitation in the visual assessment. But paper makers are adding significant amounts of OBA in print substrates while majority of the proofing stocks remain non-brightened.

ISO 13655 (2009) specifies four measurement conditions that can be used to differentiate what measurement light source is used in a measurement: (a) M0 is the legacy instrument whereby the UV contents are different between instrument manufacturers, (b) M1 is the standard D50 spectral power distribution, including the UV portion, and is designed to measure objects containing optical brightening

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agents (OBAs), (c) M2 is the measurement condition where UV has been filtered out of the light source, and (d) M3 is the measurement condition where polarizing filters are used to reduce the difference between a wet sample measurement and a dry sample measurement. This research uses M1 measurement condition to measure color prints on brightened and non-brightened substrates.

The basic principle of color management follows what is commonly known as the 'A-B-A' model. Namely, color specified by the source ICC profile (A space) is converted to the Profile Connection Space (B space), and then to the destination ICC profile (B-to-A conversion). In soft proofing, the source is the printer color space and the destination is the monitor color space. The color rendering intent is 'Absolute Colorimetric' that preserves the white point of the source media and maps it to the destination color space.

ISO 14861 (2011) specifies three soft proofing scenarios: a soft proof displayed on a monitor (a) without an associated viewing cabinet, (b) with an associated view cabinet that has a different surround, and (c) integrated into a viewing cabinet. The third scenario allows for simultaneous viewing by putting the print sample and soft proof side-by-side in the same surround. The third scenario is used in this research.

Literature Review

When both hardcopy proof and print are made on non-brightened stocks, using standard printer ICC profile produces proof-to-print color match. When printing on OBA brightened stocks, standard proof on non-brightened substrate no longer match the brightened print (Chung, 2011). This is because the standard printer ICC profile does not describe the color characterization of brightened stocks. Using the substrate-corrected colorimetric aims (SCCA), as specified by ISO 13655 (2009), the tri-stimulus linear method corrects the misalignment between the characterized reference printing condition (CRPC) and the actual printing condition (APC). The substrate-corrected dataset has been demonstrated to achieve color match between brightened print and non-brightened hardcopy proof (Chung, 2013). This research is intended to adapt the substrate-correction technique to soft proofing.

To verify the effect of OBA in source profile, the first research question is, "Is there a significant association between the source ICC profile and its soft proof performance?" The second research question is, "Will the source ICC profile, generated from the SCCA dataset using M1 metrology, improve soft proof-to-brightened print match?"

If the source ICC profile generated from the SCCA dataset using M1 metrology improves the soft proof-to-brightened print match, it will revitalize the ICC color management with new measurement devices, soft proofing procedures, and sustained benefits for printers and print buyers.

Methodology

The methodology in this research is divided into five parts: (1) soft proofing hardware setup, (2) test sample and ICC profile generation, (3) soft proofing application interface, (4) observer screening, and (5) psychometric experiments.

1. Soft proofing hardware setup

The host computer is a Mac Pro computer with a Cinema Display for logistics purpose. The monitor for soft proofing is an Eizo CG242W monitor, placed inside a GTI integrated viewing booth (Figure 1). The ambient condition is dim and the viewing booth conforms to ISO 3664 (2009) P2 condition.

Figure 1. *Integrated soft proofing system*

2. Test images and ICC profile generation

Test images include the IT8.7/4 color characterization target and five pictorial color images, including a blank page, are selected (Figure 2). These images are processed using the Kodak Approval system and transferred on to brightened print (Invercote G) and non-brightened print (Invercote T). They represent hardcopy prints in the psychometric experiments.

Figure 2. *Test images representing different pictorial scenes*

The full dataset of the IT8.7/4 prints (Invercote T and Invercote G) are measured using i1 Pro2 (M1). The substrate-corrected dataset, based on the white point of the brightened (Invercote G) stock is derived with the use of the tristimulus linear correction (SCCA) calculator. Three source ICC profiles are built using the i1 Publish: two from the fully characterized datasets (Invercote T and Invercote G) and the third from the substrate-corrected (Invercote G) dataset.

The Eizo CG242W monitor, conforming to ISO 12646 requirements in terms of white point, luminance, gamma, and uniformity, is calibrated using the X-Rite i1 Profiler. In addition, a custom Eizo monitor profile is built using the X-Rite i1 Profiler.

3. Soft proofing application interface

All ICC profiles are placed in the ColorSync Profile folder and are accessible by the Adobe Photoshop for soft proof display. When comparing a test image, the hardcopy is placed in the integrated viewing booth, and the digital image is displayed by the Eizo monitor in Photoshop CS6 with the following settings: (1) unchecked "Use Black Point Compression" and "Use Dither" under the "Conversion Options" section in Color Settings, (2) set the proofing view, View > Proof Setup > Custom > select the sample ICC profile embedded in image in the "Device to Simulate" box, check "Preserve CMYK Numbers" and "Simulate Paper Color".

4. Observer screening

The Farnsworth-Munsell 100 Hue Test is used to select qualified observers. Those who are categorized as average or superior color discrimination by the scoring software are qualified to participate in the experiment. Thirty-three candidates took the FM 100 Hue Test, and 30 of them are qualified to participate in the experiment.

5. Psychometric experiments

All psychometric tests are conducted in two soft proofing configurations. In the first configuration, a test image embedded with the non-brightened print (Invercote T) profile is displayed on the monitor as the soft proof. Two prints (Invercote T and Invercote G) of the same test image are placed on either side of the monitor (Figure 3). The observer is asked to judge which print matches closer to the soft proof. Next, the soft proof was changed to the test image embedded with the brightened print (Invercote G) profile, with the same two prints for comparison. The experiment is then repeated for the remaining test images.
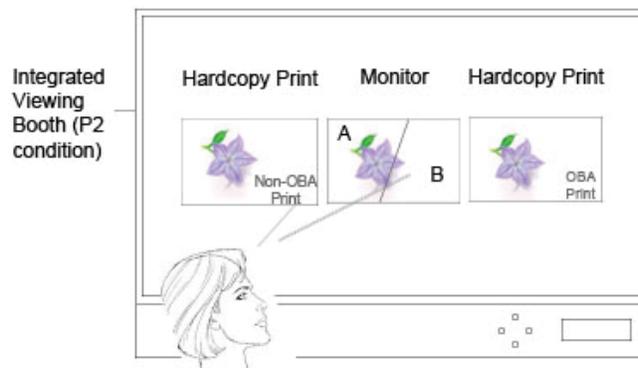

Figure 3. *Soft proofing configuration in the first experiment*

In the second configuration, only the brightened print (Invercote G) is placed next to the soft proof (Figure 4). There are three soft proofs (labeled as X, Y, and Z) that are displayed sequentially.
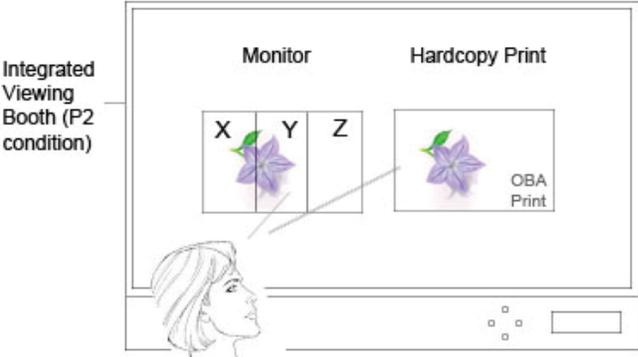

Figure 4. Soft proofing configuration in the second experiment

The three soft proofs differ in their source ICC profiles, namely, one source profile is from the non-brightened measurement (incorrect dataset), one source profile is from the brightened measurement (correct dataset), and one built from the substrate-corrected dataset. The observer is asked to provide a rank order in terms of the monitor-to-brightened print color match.

Results and Discussions

Major findings

The Chi-Square test is used to test the hypothesis, "Is there a significant association between the source ICC profile and its soft proof performance." The results show that all of the null hypotheses are rejected with the exception of Image 4 (Yellow) in the first experiment.

	Image 1 White paper	Image 2 High Key	Image 3 Low Key	Image 4 Yellow	Image 5 Magenta
Expt. 1	Reject	Reject	Reject	Do not reject	Reject
Expt. 2	Reject	Reject	Reject	Reject	Reject

Table 1. Summary of Chi-Square test results

We conclude that there is real difference between the CRPC and the APC where OBA is the main contributor of the color difference. In addition, the reason that Image 4 (Yellow) having different outcome than all other test images is because (1) the scene in Image 4 has strong yellow dominance, and (2) the short wavelength energy, contributed by the OBA, is absorbed by the yellow ink and never reaches to the eye.

For the psychometric test using the second configuration, the results show there is a significant difference between the incorrect profiles (Invercote T) embedded in an image and the correct (Invercote G) profiles embedded in an image. But, there are two correct profiles: one built from the fully characterized dataset (Invercote G), and the other from the substrate-corrected dataset (Invercote G). Upon further analyses, the test results of Image 5 (Magenta) show that the soft proof using the fully characterized dataset as the source profile has the best color matching performance. But the test results of Image 3 (Low-key) and Image 4 (Yellow) show that the soft proof using the substrate-corrected dataset as the source profile has the best color matching performance.

Sources of error in soft proof-to-brightened print match

Possible errors in the soft proof-to-brightened print match include the wrong source ICC profile, proofer calibration, and wrong soft proofing procedures. These errors are controllable and are minimized in this research.

The other source of errors in the soft proof-to-brightened print match is due to the incomplete correction of the dataset based on the white point of the printing paper. In their research, Chung and Tian pointed out that the SCCA method corrects one-third of the OBA-induced color differences (Test Targets, 2011). This is the reason that we include the full dataset and the substrate-corrected dataset in the construction of the source ICC profile and in the psychometric tests. But we are not able to demonstrate there is a real difference between them.

Another source of errors in the soft proof-to-brightened print match is due to color contents of the test images. In his research, Felix Brunner demonstrated how pictorial color image contents influences visual tolerances and proposed multi-level tolerance schemes in process control (TAGA, 1987).

To describe the impact of image contents on soft proofing performance, the following procedure is used to describe the quantitative color differences as a cumulative relative frequency between a test image pair:
   a) Converted the test image to a very low resolution image (130 pixels in total) in Adobe Photoshop;
   b) Used Color Worksheet feature in ColorThink Pro to obtain the ΔE_{00} value list for all 130 samples between the Invercote T profile and the Invercote G profile;
   c) Transferred ΔE_{00} values into Microsoft Excel, sort them, and then expressed the rank order in terms of percent of total samples; and
   d) The percent rank numbers were plotted as CRF (Cumulative Relative Frequency) curves against the ΔE_{00} values in Excel, shown in Figure 5.
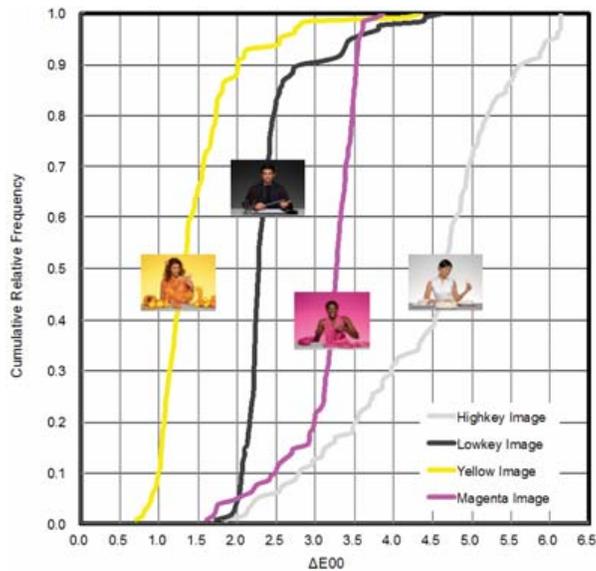
Figure 5. *CRF curves of four pictorial test images*

There are less color differences in Image 4 (Yellow) and Image 3 (Low-key). This is why observers failed to differentiate the Invercote T and Invercote G soft proofs for these images in the first psychometric experiment. However, there are more color differences in Image 2 (High-key) and Image 5 (Magenta). This means that the influence of OBA, in terms of the degree of mismatch, depends on image contents.

Conclusion

This research investigated the relationship between different source ICC profiles embedded in soft proofs and prints. The results indicate that soft proofs and prints can cause mismatch in a soft proofing environment due to the influence of OBA, but the degree of mismatch depends on image contents. For example, images with high ink coverage and predominant yellow color will have less perceived color difference between the soft proof and the brightened print. The results also indicate that both fully characterized and SCCA solutions can improve soft proof-to-brightened print match.

A custom ICC profile, built from a fully characterized dataset, performs the best in soft proofing. But a custom ICC profile for every job is not practical in routine print production because of the required test print, including the IT8.7/4 characterization target, and associated costs. Therefore, SCCA is a reasonable solution for new jobs that have not yet been printed. As long as the white point of the actual paper (M1) used in production is known, the SCCA profile can be applied in a soft proofing workflow to predict the color appearance of the brightened print.

Acknowledgments

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Introduction

- Standard datasets and ICC profiles do not account for the OBA factor.
- Print buyers prefer printed colors using OBA-loaded papers.
- Color mismatch occurs between OBA-loaded prints and non-OBA hardcopy proofs.

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Problem Statement

- To overcome the color mismatch, substrate-corrected colorimetric aims (SCCA), acting as the source profile in the color proofing workflow, improves the color match between brightened print and non-brightened hardcopy proof (Chung, 2013).
- Will the SCCA method improve the color match between brightened prints and a soft proofing system?

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Literature Review

- ICC color management (A-B-A)
    - *Source ICC profile – account for OBA via SCCA*
    - *Destination profile – calibrated media and device*
    - *Rendering intent – Absolute colorimetric*
- M1 workflow
    - *M1 measurement condition, per ISO 13655 (2009)*
    - *M1 viewing condition, per ISO 3664 (2009)*
    - *Soft proofing scenario, per ISO 14861 (2011)*

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Research Questions

1. Is there a significant association between the source ICC profile and its soft proofing performance?

2. Will the source ICC profile, generated from the SCCA dataset using M1 metrology, improve soft proof-to-brightened print match?

Note: Substrate-corrected colorimetric aims (SCCA) is defined as "color characterization data that are corrected for the colorimetric difference between production and the reference substrate" (CGATS TR016).

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Methodology

- Soft proofing hardware setup
    - *Integrated viewing conditions*
        - Eizo CG242W monitor
        - GTI integrated viewing booth
- Test sample and ICC profile generation
- Soft proofing application interface
- Observer screening
- Psychometric experiments

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Slide 7

Methodology

- Soft proofing hardware setup
- Test samples and ICC profile generation
  - *roman16 bvmd Reference Images*
  - *Hardcopy reference on Invercote T (non-OBA) and Invercote G (OBA)*
- Soft proofing application interface
- Observer screening
- Psychometric experiments

| Image 1 | Image 2 | Image 3 | Image 4 | Image 5 |

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Slide 8

Methodology

- Soft proofing hardware setup
- Test sample and ICC profile generation
- Soft proofing application interface
  - *The monitor profile, based on D50 white point, 120 cd/m² luminance, and 2.2 gamma, gave the best match.*
  - *Soft proof display in Adobe Photoshop*
    - View > Proof Setup > Custom > select the sample ICC profile embedded in image in "Device to Simulate" box > check "Preserve CMYK Numbers"> check "Simulate Paper Color" > OK
- Observer screening
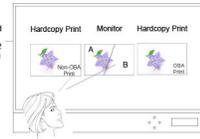- Psychometric experiments

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Methodology

- Soft proofing hardware setup
- Test sample and ICC profile generation
- Soft proofing application interface
- Observer screening
  - *Farnsworth-Munsell 100 Hue Test*
  - *30 qualified observers out of 33 candidates*
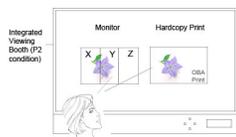- Psychometric experiments

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Methodology

- Soft proofing hardware setup
- Test sample and ICC profile generation
- Soft proofing application interface
- Observer screening
- Psychometric experiments
  - *Experiment 1*
  - *A = Invercote T profile-embedded image*
  - *B = Invercote G profile-embedded image*

Integrated Viewing Booth (P2 condition) — Hardcopy Print — Monitor — Hardcopy Print

Non-OBA Print — A — B — OBA Print

Does color match depend on hardcopy type and the source profile used in soft proofing?

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Slide 11

Methodology

- Soft proofing hardware setup
- Test sample and ICC profile generation
- Soft proofing application interface
- Observer screening
- Psychometric experiments
  - *Experiment 2*
    - X = Invercote T profile-embedded image
    - Y = Invercote G profile-embedded image
    - Z = SCCA profile-embedded image

Integrated Viewing Booth (P2 condition) — Monitor — Hardcopy Print

X Y Z — OBA Print

Which source profile, used in soft proofing, matches the OBA-loaded print the best?

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Results

- Hypothesis testing
  - *Chi-Square test analysis in SPSS at 0.05 level of significance*

	Image 1 White paper	Image 2 High Key	Image 3 Low Key	Image 4 Yellow	Image 5 Magenta
Expt. 1 (H_0: there is no association between prints and types of profile embedded)	Reject [1]	Reject	Reject	Do not reject [2]	Reject
Expt. 2 (H_0: there is no association between types of profile embedded and match performance)	Reject	Reject	Reject	Reject	Reject

[1] "Reject null hypothesis" means there is significant association between print samples and types of profile embedded in image.

[2] "Do not reject null hypothesis" means there is no association between types of profile embedded in image and soft proof-to-OBA print match performance
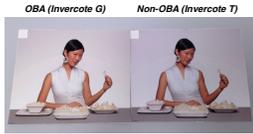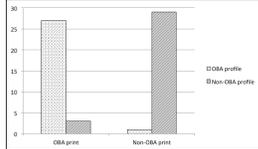
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Results and Discussion

- Experiment 1
  - *Soft proofing performance, with the exception of Image 4 (Yellow), depends on the correct source ICC profiles and the hardcopy type combination.*
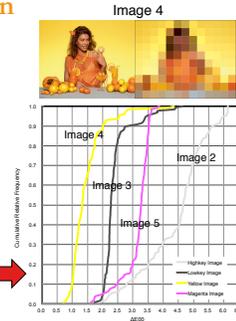
[Experiment 1 - Image 2]

OBA (Invercote G)   Non-OBA (Invercote T)

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Results and Discussion

Image 4

- Experiment 1
  - *Why is Image 4 (Yellow) the exception?*
    - The OBA effect is mainly in the blue region. But yellow predominant image absorbs blue light.
    - Quantitative analysis of the pixelated image indicates that there is less color difference (cumulative relative frequency of ΔE_{00}) in Image 4 than other images.
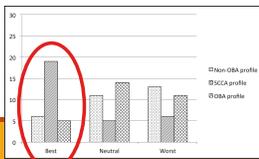
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Results and Discussion

- Experiment 2
  - *Invercote G and SCCA profiles match the OBA-loaded prints. Invercote T profile performs the worst.*
  - *SCCA profile matches OBA-loaded low-key Image 3 & yellow image 4 better than fully characterized Invercote G profile.*

[Experiment 2 – Image 3]

Image 3

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Conclusions

- OBA causes color mismatch between soft proofs and brightened prints.
  - *The degree of color mismatch depends on image contents.*

- Both fully characterized and SCCA solutions can improve soft proof-to-brightened print color match.
  - *SCCA is a reasonable solution for new jobs that have not yet been printed.*

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