The Effect of Spectrocolorimeter Reproducibility on a Fully Color-managed Print Production Workflow

Danny C. Rich, Yoshio Okumura, Veronika Lovell; Sun Chemical Corporation, Color Research Laboratory, Carlstadt, NJ / USA

Abstract

In a modern color-managed print production workflow, it is assumed that the color measurements produced at various stages of the production workflow are fully inter-relatable. In this paper we examine that assumption by comparing the output of a range of spectrocolorimeters on the same basic test target. The statistics of the readings are then used to compute expected and worst case errors in the color measurements that are used to characterize the work flow. The errors are propagated from the ink supply following ISO 2846, through the finger printing of the press and the proofer following the protocols established in ISO 15076 and then for process control following ISO 12647.

Introduction

In the modern publication or packaging printing workflow, the ink maker utilizes high performance spectrocolorimeters costing tens of thousands of dollars and measures large area (up to a 20mm diameter spot) specimens to provide maximum reliability and repeatability in the characterization of the inks. These instruments are too large, too slow and too expensive to use in the characterization of printing presses, digital presses or proofing printers. Instruments for characterizing the color of printing are supplied in many different formats, some offering manual scanning of color targets, some offering automated mechanical scanning of targets and some providing fixed scanning of targets while the print substrate is moved under the colorimeter head. Each of these approaches presents the instrument engineer with a number of difficult compromises to address.

Reports by Wyble and Rich[1],[2] have indicated that many, portable, hand-held spectrocolorimeters have extremely good precision but different instruments produced consistently different results on standard materials, like ceramic tiles, sintered PTFE and high performance printing inks. They reported differences as large at 6 CIELAB units with averages between 1 and 3 CIELAB units. In scanning systems, there is no mechanical contact between the sampling aperture of the instrument and the specimen surface and so errors due to stray light, lateral diffusion and geometric misalignment could become greater. To date, no one has reported on comparisons of benchtop, handheld and manual or automated scanning instruments, even though the readings from these various spectrocolorimeters are used interchangeably in a digital workflow. Their importance become even more critical as the ISO together with the ICC is now offering “blind exchange” of preprint data, including embedded source and destination profiles and print production trade organizations are adopting press calibration and characterization protocols, such as the G7 process, that assume complete agreement between the color measurements at different stages of the print production process.

Experiment

In this study a test target was prepared using colors taken from the X-Rite Digital ColorChecker® SG chart[3] and printed on a durable print substrate using an archival quality digital printer[4]. This substrate and ink system has been documented to show no significant color shift over a period of 10 years.

While every effort was made to obtain an accurate reproduction of the patches, it is not necessary that the print exactly match the chart since the goal is to test the agreement between various instruments and not the agreement between each instrument and some nominal characterization of the chart. A subset of 177 patches was selected from the full chart, eliminating the many redundant neutral patches and the nominal CIELAB values of the patches were input as spot colors into Adobe Photoshop® CS3 software[5] to create test charts that could scanned as well as measured manually.

The printed target was submitted to several automatic scanning spectrocolorimeters, manual scanning spectrocolorimeters and hand-held laboratory spectrocolorimeters. The instruments included the following: an X-Rite 968, X-Rite 939, X-Rite SpectroEye, X-Rite DTP-20, X-Rite DTP-70, X-Rite EyeOne pro and the EyeOne pro on an IO scanning system.

The measurement routines were setup to export the spectral reflectance factor data into an ANSI CGATS.17 Graphic technology — Exchange format for color and process control data using XML or ASCII text [6] compatible exchange file and then imported into Excel. The ASTM E308 Standard Practice for Computing the Colors of Objects by Using the CIE System [7] Table 5.9 was used to generate tristimulus values for CIE D50 and the 1931 Standard Observer functions for a 2° visual field. The tristimulus values were converted to CIELAB coordinates and the color differences between each pair of instruments and between each instrument and the average of all readings were computed. For a subset of the instruments, the readings were repeated 5 times on different days. This would allow a determination of the precision of the readings and standard deviations of the determinations as described in reference 1.

Results

As anticipated, the differences between instruments can be quite significant. Maximum differences of up to 4.0 CIELAB units were observed between pairs of the instruments used in this study. In the study reported by Wyble and Rich the pair-wise contrasts had average differences between 0.5 and 2.9 CIELAB units with the maximum differences of 6 CIELAB units for ink samples using bidirectional instruments. In an unpublished internal program on a gauge R&R for SixSigma, eight instruments, four sphere-based and four bidirectional (45:0) were compared. These instruments are in use in ink production facilities. The results of those contrasts were such that for the sphere instruments, the pair wise average difference was 0.11 CIELAB unit with a maximum difference of 0.38 CIELAB units and for the bidirectional instruments, the average difference was 0.24 CIELAB unit and the maximum difference was 1.0 CIELAB unit. The poorer level of reproducibility for bidirectional (45:0) instruments has been reported in every study in the literature that compares geometry with reproducibility.

A propagation of error or uncertainty analysis begins with the ink color on the non-commercial substrate, APCO II/II, as specified by ISO 2846. There is a tolerance allowed on the color of the inks in terms of CIELAB ΔE^*_{ab} of approximately 4.0 units for paste inks and about 5 units for fluid inks. Generally, someone utilizing a color managed workflow will not know the exact results of the statistical analysis of the ink manufacturing process. As indicated above, the characterization of the ink can be held to quite tolerances because the instruments involved have a high reproducibility. However, from vendor to vendor or from chemistry to chemistry the exact location of the specific ink may fall anywhere within the ISO allowed tolerances. Therefore, the exact color of the ink becomes a Type A uncertainty or an uncorrectable systematic error.

The methodology for taking a fixed uncertainty and adding random or Type B uncertainties to it can be found in the Guide to the Expression of Uncertainty in Measurements (GUM)[8]. For the graphic arts, the primary source of guidance comes from ISO 15790 Graphic technology and photography —Reflection and transmission metrology — Certified reference materials — Documentation and procedures for use, including determination of combined standard uncertainty[9] and will be followed here. The Type B uncertainties, those obtained from the experiment include the repeatability and the reproducibility ranges. Snedecor and Cochran[10] give a method to convert a measured range, from a small number of readings into an equivalent standard deviation which can then be used in statistical tests, such as the error analysis described here. We will thus use the range of CIELAB ΔE^*_{ab} values to derive the required standard deviations. For a small number of readings (5 in this experiment) the standard deviation is approximated by dividing the range by 2. Thus the expression for the total expected error in a work flow will be the sum of the errors or uncertainties in each step of the workflow, as shown in equation 1.

$$DE(process) = \sqrt{[(DE^2(2846) + DE^2(12647) + DE^2(test)]} \quad (1)$$

Moving from ISO 2846 through to ISO 12647, as recommended in a G7 calibration protocol, one finds that there are again tolerances on the transfer of the ink to a production substrate, (identified as Types 1 to 5 papers). Then the characterization data from the press or proofer must be combined with the ink and press calibration data. The combinations are then combined in quadrature – the systematic errors with the random errors and the square root is computed. The coverage factor, k, is applied to provide a confidence interval. In most cases the coverage factor is set to 2 which is approximately a 95% confidence level. In the situation at hand, the ranges are: 4 for the inks, 5 for the printing, 6 for the test characterization, Thus the expected error at the k=1 level will be between 4.4 and 5.6 CIELAB units depending on how whether the ink error is treated as Type A or Type B. If the coverage factor is raised to k=2, then the errors will be 8 to 11 CIELAB units.

Discussion and Conclusions

Two possible scenarios can be conceived from these results. First, it is possible that visually acceptable ink and printing may result in a numerical failure when the measurement data from the two ends of the workflow are compared. This we classify as a false positive. Secondly, it is possible that a visually unacceptable ink may result in a numerically acceptable instrumental assessment. This we classify as a false negative. If either error occurs, the blind exchange of data will be affected and the users of the color management system will be disappointed. It can be speculated that many of the reports of failures of color management in a blind workflow may be traceable to such reproducibility errors.

More work needs to done to better understand the geometric effect of high speed instruments relative to the more stable and accurate benchtop or laboratory instruments. One tool that can be used to assess and perhaps correct this potential pitfall, is the use of an instrument profiling process such that the readings of scanning instrument can be adjusted so that they are in closer agreement with the laboratory instruments. From the literature cited in the introduction, it is apparent that the ink suppliers have their measurement systems in good control and thus could be used as the reference to which printing and proofing process control and characterization instruments are anchored.

References

[1] David R. Wyble, Danny C. Rich, "Evaluation of methods for verifying the performance of color-measuring instruments. Part I: Repeatability", *Color Research & Application*, Volume 32, Issue 3, Date: June 2007, Pages: 166-175.

[2] David R. Wyble, Danny C. Rich, "Evaluation of methods for verifying the performance of color-measuring instruments. Part II: Reproducibility", *Color Research & Application*, Volume 32, Issue 3, Date: June 2007, Pages: 176-194.

[3] *G7* is a trademark of IDEAlliance, 1421 Prince St., Suite 230, Alexandria, VA 22314-2805.

[4] *Digital ColorChecker SG*® is a product of X-Rite, Inc., 4300 44th St. SE, Grand Rapids, MI 49512 USA, 01-616-803-2100.

[5] The print system used in this experiment is a *ChromaLife100*™ system manufactured by Canon, Inc. The system used here was a *Pixma Pro 9000*™ printer, *CLI-8*™ inks (8 colors) and PR-101 *Photopaper Pro*™ (glossy).

[6] *Photoshop*® *CS3* is a product of Adobe Systems Incorporated. 345 Park Avenue, San Jose, CA 95110-2704, 408-536-6000.

[7] These instrument names are all products of X-Rite, Inc., 4300 44th St. SE, Grand Rapids, MI 49512 USA, 01-616-803-2100.

[8] ANSI CGATS.17 - 2005, *Graphic technology — Exchange format for color and process control data using XML or ASCII text*, NPES Publication Sales, 1899 Preston White Drive, Reston, VA 20191-4367, USA, 01- 703-620-0994.

[9] ASTM E 308 – 06, *Standard Practice for Computing the Colors of Objects by Using the CIE System*, ASTM International, 100 Barr Harbor Drive, PO Box C700, West Conshohocken, PA 19428-2959, United States, 01- 610-832-9585.

[10] *APCO II/II* is a product of Papierfabrik Scheufelen GmbH + Co. KG, Adolf-Scheufelen-Straße 26, 73252 Lenningen, Germany

[11] ISO 2846 – 200x, *Graphic technology - Colour and transparency of ink sets for four-colour-printing – Parts 1 – 6*, ISO Central Secretariat, 1 rue de Varembé, 1211 Geneva 20 Switzerland. 41-22-749-0111.

[12] *ISO Guide to the Expression of Uncertainty in Measurement*, 1995, ISO Central Secretariat, 1 rue de Varembé, 1211 Geneva 20 Switzerland. 41-22-749-0111

[13] ISO 15790:2000, *Graphic technology and photography — Reflection and transmission metrology — Certified reference materials — Documentation and procedures for use, including determination of combined standard uncertainty*, ISO Central Secretariat, 1 rue de Varembé, 1211 Geneva 20 Switzerland. 41-22-749-0111

[14] George W. Snedecor and William G. Cochran, *Statitical Methods*, 6th Edition, Iowa State University Press, Ames, Iowa, USA, (1978).

[15] ISO 12647-1, *Graphic technology — Process control for the production of half-tone colour separations, proof and production prints — Part 1: Parameters and measurement methods*, ISO Central Secretariat, 1 rue de Varembé, 1211 Geneva 20 Switzerland. 41-22-749-0111.

Author Biography

Danny Rich received his BS in physics from the University of Idaho (1973), his MS in physics from Virginia Polytechnical Institute (1977) and his PhD in Color Science from Rensselaer Polytechnic Institute (1980). He has worked in the Research Centers of the Sherwin-Williams Company in Chicago, IL, Datacolor International, and Sun Chemical. He is the senior Color Physicist in the Sun Chemical Color Research Laboratory.

Veronika Lovell received her BS in chemical engineering from the Slovak University of Technology(2000), her MS in Paper and Imaging Science and Engineering, Western Michigan University(2003) and her PhD in Paper Engineering, Chemical Engineering, and Imaging, Western Michigan University(2006). She received the 2007 Itek Award for an outstanding original student publication in the field of imaging science and engineering. She is a Color Engineer in the Sun Chemical Color Research Laboratory

Yoshio Okumura received his B.E. degree in electronics from Doshisha University(1997) and his M.S. degree in Color Science from Rochester Institute of Technology(2005). He is a Color Scientist in the Sun Chemical Color Research Laboratory.

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