Accuracy and Consistency of Instruments Used for Emissive Color Measurement

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Abstract: The evolution of several imaging technologies are examined relative to proofing applications with the purpose of identifying general requirements for color proofing. Once framed within the context of requirements for proofing, the accuracy and consistency of measuring devices used to characterize emissive color output devices are considered. Results indicate that measuring instruments used by non-research establishments to characterize the color of emissive imaging devices were less accurate and consistent than expected.

Introduction

In color printing, a proof is the stake in the ground or, the "promise" of what the, final, printed output will look like. A signed off proof is a contract between a specifier and printer, and therefore, proofing technology must be both very accurate and very consistent. At Print '01, some vendors reintroduced "soft proofing," a technique using the output a color emissive screen, a Cathode Ray Tube (CRT), for use as a color proof. It is highly likely that the output of such systems will be used to proof images that are being produced at different locations and comparisons against different vendor's hard and/or soft copy proofs will be encountered. Since the judges of such images perceive color differently, prudent shops normally rely on both visual and numeric data from either or both hard and soft proofs as the criteria for image acceptance. Therefore, the image quality of soft proofing technology must be equal to or better than that imposed upon hard copy proofing technology. This paper is concerned with requirements for image quality metrics associated with color accuracy and consistency necessary to qualify new proofing technology for use in contract proofing in the graphic arts industry. And in this context, the instrumentation used to quantify the performance of imaging systems is studied.

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[1] Dominant Wavelength
[2] Kodak Polychrome Graphics

First, the evolution of color proofing technology is discussed to provide the reader with background information concerning the progression from analog to digital and wet to dry proofing. Successes and pitfalls experienced with past techniques are noted. These provide guidance in the attempt to determine the criteria necessary for color accuracy and consistency for today's and tomorrow's color printing and proofing technologies.

Because today's digital imaging technology relies heavily on numerical data, the topics of color measurement device metrology and calibration are also discussed. Metrology and calibration are used to evaluate measured values against known color standards and facilitate the absolute comparison of measured values from different sources by making measured values device independent. Metrology and calibration provide the means by which measurement uncertainty can be determined.

Finally, this paper investigates the consistency of measuring devices used to characterize color CRT monitors sold for soft proofing purposes. In particular, information is presented on:

1. The use of Certified Reference Materials, CRMs, and,
2. The accuracy and consistency of emissive color measurement devices.

Evolution of Proofing and the Requirements for Proofing

Lessons from the past provide valuable insight into the requirements for proofing. Every printed job is custom made and the ability to preview a bespoke printed color piece is vital to its acceptance. Therefore, proofing is the economic concern of the specifier, producer and printer. Since color is created in the eyes and mind of the beholder, the ability to predict and communicate the color of a printed piece is crucial and is the function of proofing. Proofing is a distributed process that facilitates constituencies from near and remote locations to evaluate the visual and numeric appearance of the preview of a given print job. The requirements for accuracy and consistency in color proofing are best exemplified by examining the evolution in color proofing.

Originally, offset color proofs from camera separated films were produced using a proof press or a short commercial press run. At that time, the colors produced by the manufacturer's inks differed from one another. The proofs produced, therefore, varied not only between the ink sets available, but also in color tone reproduction. Press proofs from tightly controlled environments can vary by as much as 6 delta E (Siljander, Fisch, 2001). Generally, buyers expect printed materials to be within 6 delta E of proofs (Williamson, 1998).

In the late 1950s and middle 60's new technology was introduced that allowed the production of off-press proofs made using photographical and photomechanical methods. This new technology was developed to simulate printed color. With typical reproducibility within 2 delta E, the new technology was widely accepted because it was very consistent – significantly more consistent than press proofing.

Through the years since then, various other technologies have been presented to the graphic arts industry. They, however, were not generally accepted until the middle 90s when digital technologies started to offer levels of accuracy and consistency the industry learned to expect from earlier photomechanical technologies. The recent and rapid evolution of digital technology has resulted in a proliferation of proofing technologies and a clear stratification of proofing technologies has emerged. Those technologies with superior color accuracy and consistency are used for color critical contract proofs while less accurate or consistent technologies are used for content proofs.

Inkjet proofing is a classic case for studying the requirements necessary for contract proof acceptance. Several have reported and summarized the history and use of inkjet technology and its application in graphic arts proofing (Fisch, 1998; Bruno, 1986). Originally, the color appearance and light color stability of most low and medium priced ink jet proofers was poor, limiting their commercial use to in process, concept graphics and short run display printing. In publications printing, inkjet technology first appeared in the form of imposition proofing systems for economical reasons – low cost equipment and supplies as well as high productivity. As manufacturers of inkjet systems developed better hardware and consumables technology, inkjet technology gained ability to better simulate given color objectives and increased in consistency. With these technological advances, inkjet technology gained more acceptance for use in color intensive applications, although, it is generally not accepted for contract proofing.

Today, we are faced with the reintroduction of cathode ray tubes, CRTs, which have been widely used in content applications for decades. CRTs have been under scrutiny for color critical proofing applications for more than a decade, but their transition into the color critical arena has been impaired by several technical deficiencies. Studies have been undertaken to evaluate the viability of CRT based proofing systems for color critical applications (Williamson, 1998; Fuhs, 1988), but, panels of subjective observers have, until recently, rejected the hypothesis that soft proofing is a viable proofing alternative for any application other than that of content proofing. In the Fuhs and Williamson reports, among other issues, color accuracy and consistency were of primary concern to the observers.

For any proofing technology, general acceptance by the industry appears to be directly correlated with two key items:

1. The ability to target the output color (Accuracy), and,
2. The ability to maintain stable output color (Consistency).

In the early days of photomechanical proofing, these items were largely controlled by the vendors of the proofing systems and through the use of simple process control devices like gray cards (image capture) and gray scales (image output). The proliferation of digital technology has decentralized control from vendor's factories to the end-user's shop. Control systems no longer rely on simple control devices, but rely almost entirely on densitometric and colorimetric data. For this reason, it is necessary to understand the accuracy and consistency of the devices used to characterize CRTs.

Color Measurement Device Metrology

In the context of the requirements outlined above, can emissive imaging technology satisfy the requirements for proofing? To answer this question, it is necessary to first evaluate emissive measuring devices. That is, to raise and answer a new question: Do emissive color measurement devices demonstrate the accuracy and consistency necessary to control CRTs? In other words, if instruments used to control color output do not satisfy accuracy and consistency requirements, the color output devices controlled and characterized with those instruments certainly will not satisfy those requirements.

The evaluation and control of any measurement device is called metrology. The function of metrology is to maximize the levels of accuracy and consistency. The most common implementation of a metrology program is calibration. Calibration generally refers to the process of measuring a known sample with the purpose of deriving correction factors that may be applied to measured values. In distributed processes like remote proofing, calibrating to standard references is necessary to maintain consistency between remote locations.

For hard copy measurement applications, acquiring standard references for calibration is not a problem. Color measurement instrument manufacturers supply Certified Reference Materials, CRMs, in the form of a characterized reflection samples. Sometimes several CRMs of different colors are provided. These CRMs generally take the form of paper samples or ceramic plaques and are referenced to National Institute of Technology Standards, NIST, sources. Importantly, reflective CRMs are relatively inexpensive.

For soft copy measurement applications, reliable calibration procedures do not generally exist because emissive CRMs are not supplied by manufacturers of handheld, inexpensive instruments. This omission is largely due to the exceedingly high cost of maintaining sources of highly controlled illumination. This omission prohibits the evaluation of emissive color measuring devices for the bulk of the graphic arts industry. Without a means to calibrate instruments to known sources, users of emissive technology have no means of verifying or validating any color measurement data.

The experimental data presented in this paper was collected using devices referenced to a telespectroradiometer, a tertiary CRM. The technique used to calibrate the telespectroradiometer was codified in the certificate of compliance provided by the calibrating laboratory and was in compliance with MIL, ISO and ANSI specifications (Photo Research, 2001).

Emissive Instrumentation Performance

A series of experiments were performed to quantify the accuracy and consistency of commercial emissive color measuring devices. It was found that the consistency and device independent nature of such instruments were less accurate and consistent than that expected from them. This undermines their usefulness for controlling the job at hand and the reliability of the proof produced. While the complete level of performance is found by examining all pieces of the emissive output system, this experimentation focused on within and among instrument uncertainty.

Consistency was considered in terms of the ability of an instrument to reproduce its own results; the ability of instruments of the same manufacturer and model to reproduce the results of each other; and, the ability of instruments from different manufacturers or different models to reproduce each other's results. Three different instrument families (model/manufacturer) were tested. For each family, five replicated sets of data were collected from five instruments. Each set of data was randomly interleaved with data collected from the other devices such that systematic errors associated with dwell times or other unknown factors could be minimized. Colors presented to the measuring devices included various levels of primary reds, greens and blues, secondary cyans, magentas and yellows, and, three color grays resulting in 18 colors approximately uniformly covering, albeit sparsely covering, the gamut. This sampling resulted in 75 sets of data from which the stability of the emissive source, a CRT, could be verified and, from which the consistency of the measuring devices themselves could be determined.

Results of this experiment are presented in the following table. In this table, *Within Instrument* refers to the ability of an instrument to reproduce its own results. *Between Instruments Within Family* refers to the ability of an instruments of the same manufacturer and model to reproduce the results of each other. The last column, *Between Instrument Families* refers to the ability of devices from different manufacturers and/or models to reproduce the results of each other. For comparison purposes, the last row contains data that indicates typical performance of hard copy color measurement devices.

Measurement Consistency – Average (95th Percentile)

	Within Instrument	Between Instruments Within Family	Between Instrument Families
I_1	0.2 (1.6)	0.9 (1.3)	4.0 (5.9)
I_2	0.4 (3.3)	0.8 (1.4)	6.4 (8.5)
I_3	0.9 (1.9)	3.2 (5.0)	8.2 (13.8)
Typical H. C.	0.05 (0.1)	0.2 (0.4)	0.7 (2.0)

Table 1. Within and between color measurement device consistency. Units are delta E.

Analyzing the data through time verified the CRT remained stable through the course of the experiment. Analyzing the data by instrument shows a wide range of within and between measuring device agreement. In some cases within device agreement is as low as 0.2 delta E, but in other cases, almost as high as 1 delta E. It is hypothesized that variation between measurements made with a single instrument can sometimes be related to the apparent aperture of the instrument, but this hypothesis was not tested. Between instrument family results spans a broad range – certainly broader than the 6 delta E limit proposed by the GATF (Williamson, 1998).

Accuracy was determined by comparing the measurements from the telespectroradiometer to measurements of the same source from the device under test. In this experiment, data from three devices of the same model from one manufacturer were compared to data measured by a telespectroradiometer. Only one instrument family was considered in this case, operating under the assumption that with the accuracy of one family known, the accuracy of any other families may be determined by comparing its data to the known families data. In other words, referencing I_1 to the telespectroradiometer makes it a fourth order CRM to which the other instruments may be compared.

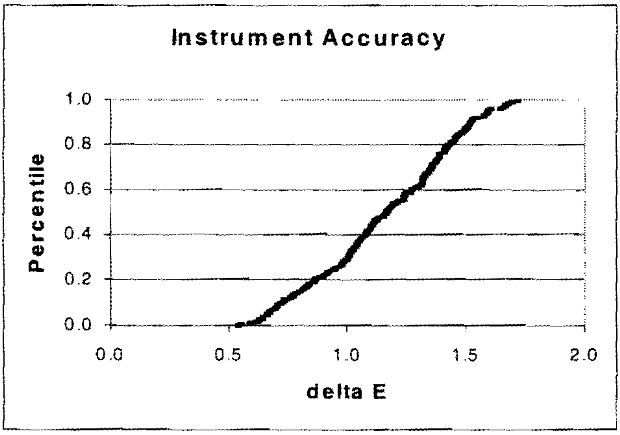
Measurement Accuracy – Average (95th Percentile)

Instrument	Accuracy
Telespectroradiometer	0.7 maximum
I_1[3]	1.2 (1.6)
I_2[4]	4.9 (8.7)
I_3[4]	11.3 (19.4)
Typical Hard Copy	0.7 (2.0)

Table 2. Color measurement device accuracy. Units are delta E.

[3] Accuracy values reported for this device are relative to the telespectroradiometer.
[4] Accuracy values reported for this device are relative to the device labeled I_1.

The following chart presents a more complete picture of accuracy using a method presented in a previous TAGA Technical Conferernce (Bartels, Fisch, 1999). This chart shows the cumulative distribution function of I_1 differences to the telespectroradiometer.



Summary and Conclusion

In the interest of developing accurate and consistent color control for emissive proofing technology, color accuracy and consistency requirements for proofing systems and the instruments used to measure the performance of emissive display devices were investigated. Analysis of hard copy proofing systems illustrates the level of control necessary for imaging devices used in the graphic arts industry for color critical proofing. Since digital systems rely heavily on numerical data for color control, instrument metrology is crucial to maintain imaging system accuracy and consistency. Even with the high level of control exercised over reflective measuring devices, many times, objectionable artifacts can be traced back to the color measuring device as described in the literature (Rich, 2002; Siljander, 1999).

Assuming that color requirements for hard copy devices apply to emissive copy devices, it follows that emissive color measurement devices must perform at levels similar to or better than that achieved with reflective color measurement devices. The experiments performed during this investigation indicate that emissive measurement devices are, at best, four time noisier than typical hard copy measurement devices. While data shows individual measurement devices and even some families of similar devices may satisfy minimum requirements, between family variations impose restrictions on the use of measurement data that certainly relegates measurement data to device dependent status.

The authors conclude that, in order for soft proofing to become a widely accepted and decentralized form of proofing, that is, to reduce the combined uncertainty of CRT output to a point below the critical threshold for color critical proofing applications, instrument manufacturers need to develop more stable instruments and agree upon economically and colorimetrically reasonable CRMs for emissive color measurement devices.

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Selected Bibliography

ASTM Committee E12

1994 "Obtaining Colorimetric Data from Video Display Unit by Specrtoradiometry Method," Publication 03-512094-14, Fourth Edition, Philadelphia, PA.

Brown, Steven W. and Ohno, Yoshi

1999 "NIST Calibration Facility for Display Colorimeters," SPIE Proceedings Vol. 3636, Bellingham, WA, pp. 162 – 169.

Bartels, Sharon and Fisch, Richard

1999 "A Colormetric Test for Reflection CMYK Colorant Output," TAGA Proceedings 1999, Rochester, NY, pp. 204 – 215.

Bruno, M. A.

1986 Principles of Color Proofing, GAMMA, Philadelphia, PA.

Fisch, Richard

1998 "Digital Color Proofing," McGraw-Hill Yearbook of Science and Technology, McGraw-Hill, New York, NY, pp. 316 – 317.

Fuhs, Sandra

1988 "A Study of the Subjective Differences Between Soft-copy and Hard-copy Proofing," Master's Thesis, Rochester Institute of Technology, Rochester, NY.

International Organization for Standardization

1995 Guide to the Expression of Uncertainty in Measurement, Geneve, Switzerland.

Juran, Joseph M. and Godfrey, A. Blanton
1999 Juran's Quality Handbook, McGraw-Hill, New York, NY.

Photo Research, Inc.
2001 PR-650 SpectraScan SpectraColorimeter Instruction Manual and Certificate of Compliance and Conformance, Chatsworth, CA.

Rich, Danny
2002 "Improving inter-instrument agreement of spectrocolorimeters," ANSI/CGATS TR 021, NPES, Reston, VA.

Siljander, Roger
1999 "Characterizing Color Measurement Devices," Gravure Magazine, Fall 1999, Rochester, NY, pp. 28 – 36.

Siljander, Roger and Fisch, Richard
2001 "Accuracy and Precision in Color Characterization," TAGA Proceedings 2001, Rochester, NY, pp. 57 – 80.

Williamson, Karl C.
1998 "Soft Proofing Characterization Study," GATF Research & Technology Report 5, GATF Press, Pittsburgh, PA.