Subject: Your paper for the IC Journal
Date: Thursday, April 7, 2016 at 8:41:50 AM Eastern Daylight Time
From: Wolfgang Faigle
To: Bruce Myers

Dear Bruce,

I hope you are well and enjoy your life, not at least your research.

And I hope you will not be too disappointed by the following news: I had to decide to postpone your paper until the next issue of the IC Journal which is due in fall this year.

For the next one - which is just being typeset and will be published later this month, the electronic version at least - I had much more material than the 30.000 words needed for a usual issue. So I had to decide what to publish and what to postpone (NOT to delete - it will be published).

It was a hard decision what to publish and what to postpone, so I used the date of the submission and a balanced composition of the issue as the guidelines.

Martin Habekost, our future editor, knows about my dilemma. We both were confident that those affected will understand my decision. Do you ?

Will we meet in Leipzig ?

Best regards
Wolfgang

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Colorimetric Variables Utilized by U.S. Ink Companies

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Brief Biography:

Bruce Leigh Myers, Ph.D. is an earned Doctorate in Graphic Communications with over twenty five years of extensive industry experience currently serving as Assistant Professor in the School of Print Media at Rochester Institute of Technology. Dr. Myers worked as a resident professor in Graphic Communications at a New Jersey State University from 2000 – 2004, and served over fifteen years as an Adjunct Instructor teaching theoretically based Graphic Communications concepts at New York University. Industry experience includes over fourteen years in various sales, management and global training positions at X-Rite, Incorporated and eleven years in technical, sales and management positions at Agfa.

Areas of specific technical expertise include color management, statistical process control, quality management, quantitative research design and analysis.

Abstract

Colorimetry is widely adopted in the printing industry, but the user-selected variables inherent in using the technologies are not widely standardized. In the present study, the current state of the adoption of particular colorimetric variables is examined in U.S. ink companies. A quantitative, cross-sectional survey was distributed to ink companies inquiring about their selection of instrument geometry, colorimetric illuminant, standard observer and color differencing method as part of their standard operating procedures. In addition, companies were asked about their choice for quality assurance software and preferred digital file format for color communication.

Keywords: color differencing, delta-e, colorimetry, standard operating procedure, CIE

1. Introduction

The widespread use of colorimetry has permeated the printing industry; colorimetric values are frequently utilized to manage and control color reproduction and commonly used in both brand color control initiatives and in printing industry standards and specifications (e.g., ISO/DIS 12647-2 (2012)). When correctly implemented, the use of colorimetry enables the concise communication of color values among stakeholders in the printing workflow. Applied in a wide-range of quality assurance (QA) applications, one key goal in the adoption of colorimetry is to drive variance out of the printing workflow. Practitioners, however, must be wary of the myriad of variables inherent in the communication of colorimetric values (i.e.: illuminant, standard observer, color differencing method). Unless properly managed, these variables could result in increasing variance in color printing processes.

2. Need for the Study

Many printers have moved from visual analysis and densitometry to colorimetric information for QA and process control: motivations range from the pursuit of continuous improvement, response to directives from their customers, and adherence to standards and specifications.

Ink companies in particular are widely regarded as being among the most influential users of colorimetry in printing workflows. The nature of the production of inks has practically mandated that manufacturers utilize colorimetry to assure production consistency. Many ink companies pro-actively provide colorimetric data in reporting with ink shipments: some go as far as to print colorimetric information on the labels of their ink containers. As printers adopt colorimetric controls, they likely consult their respective ink company for assistance in establishing their standard operating procedures (SOPs), which include the colorimetric variables examined here.

While there are numerous examples of studies that compare various color differencing methods (e.g.: Yu, 2014; Habekost, 2013; Chung & Chen, 2011) an extensive review of the literature revealed no published studies that examined which colorimetric variables are used by practitioners in this domain. Furthermore, the present study examines potential correlations that may contribute to a greater understanding here.

3. Research Questions

A cross-sectional questionnaire survey instrument designed to examine the colorimetric variables utilized as SOPs by ink companies in the United States was utilized. Specifically, the following research questions frame the investigation:

RQ1. Which instrument geometry is utilized?

RQ2. Which illuminant is selected?

RQ3. Which standard observer is selected?

RQ4. Which color differencing equation is utilized?

RQ5. Which, if any, software is utilized for QA?

RQ6. Which, if any, digital file format is utilized for colorimetric communication?

Understanding the commonly used variables in this field and possible correlations can be relevant for a number of constituencies, including printers and print buyers, industry manufacturers, educators, standards and specifications committees.

4. Literature Review

Literature germane to the present topic include published works that describe and define colorimetric variables, and those that compare and contrast those variables through psychophysical analysis.

A brief discussion of the variables examined is outlined below. Those interested in more detailed analyses are encouraged to consult the cited sources for more information on the variables introduced.

4.1 Colorimetry, CIELAB, standard observer and standard illuminants

The process of quantifying the perception of color is known as colorimetry. In industrial use, colorimetry is based on the work of the Commission internationale de l'éclairage, more commonly referred to as CIE, which is generally translated as the “International Commission on Illumination”. Established in 1913, the CIE is recognized by the International Standards Organization (ISO) as an international standardization body (Schanda, 2007.)

CIELAB is an opponent color system adopted by the CIE in 1976 as a color model based upon a standard observer and standard illuminants (Berns, 2000). It is designed to be a device-independent, universal color space representative of the range of colors perceptual to the ‘average human’ with normal color vision. The CIE has defined two standard observers: a 1931 standard observer based on a testing individuals color perception using a two degree angle of view, and a 1964 standard observer based upon testing using a ten degree angle of view (Schanda, 2007). Standard illuminants for colorimetry are representations of the spectral power distribution of light in numerical form; the CIE has defined several illuminants to represent particular light sources (Hunt & Pointer, 2011; Berns, 2000). These data are used to calculate the colorimetric values of a sample as it would appear under a light source that corresponds to the selected CIE illuminant.

When CIELAB values are derived from spectrophotometric readings, the standard observer, illuminant and spectral readings are factored to derive XYZ tristimulus values: the CIELAB values are based on those XYZ values (Berns, 2000).

4.2 Instrument Geometry

Color measurement instruments measure the light reflectance of samples relative to a particular reference. Due to the surface characteristics of the samples measured and other factors, the instrument illumination condition and the incident angle of measurement are of critical importance. As detailed in Randall (1997), “Directional” geometry instruments measure directional light at 45 degrees incident to the light source, either illuminating at zero degrees and reading at 45 degrees (0°/45°) or illuminating at 45 degrees and measuring at zero degrees (45°/0°). “Spherical” instruments, otherwise known as d/8°, utilize diffuse lighting and measure at 8 degrees. These instruments generally enable users to read with the specular component of the light source included with, or excluded from, the colorimetric reading. Multi-angle instruments, sometimes called “gonio spectrophotometers” use directional lighting and measure at several angles, often simultaneously. Instruments that measure five angles are common multi-angle devices (Davis, 1996; Teunis, 1996).

4.3 Color Differencing Equation, alternately known as colorimetric tolerancing method

The primary goal of a colorimetric differencing equation is to use objective, quantifiable measurements to replace more subjective visual analyses. Color differencing equations reduce the color difference between two samples to a single number. The CIE first published ΔE^* (alternately known as ΔE^*_{ab} and ΔE_{76}) in 1976 (Berns, 2000). This tolerancing method has been widely utilized in industry and by ISO procedures (e.g., ISO12647-2, ISO/DIS 15339 (Cheydleur, 2013; Warter, 2011)).

In practical use, however, ΔE^* proved to be limited as the CIELAB color space is not visually uniform. In response to this condition, in 1986 The Color Measurement Committee of the Society of Dyers and Colorists published an equation for determining color difference, known as ΔE_{cmc} (Hunt & Pointer 2011). The goal of the Committee was to develop a color difference formula that better handled small color differences. Later, the CIE created technical committees to examine the perceived limitations of ΔE^* (Berns, 2000). Resultant equations of the CIE's work include ΔE_{94} (alternately known as ΔECIE1994) and ΔE_{00} (otherwise known as ΔECIE2000) (Hunt & Pointer, 2011; Luo, Chi & Rigg 2000; Wyszecki & Stiles 2000).

In addition to the technical literature, a number of psychophysical studies have been published that examine which color differencing method best corresponds to human vision. Such research investigated samples with surface characteristics typical for the printing industry, and some have segregated trained and untrained observers in their analysis. These include several studies that have compared ΔE^*_{ab} to more current differencing methods in various contexts (e.g., Yu, 2014; Habekost, 2013; Chung & Chen, 2011; Habekost, 2009). Generally, these studies conclude that in nearly all examined applications ΔE_{00} outperforms ΔE^*, however in instances where ΔE_{00} is compared to other more current tolerancing methods (i.e.: ΔE_{cmc}, ΔE_{94}) results are less conclusive.

5. Research Design and Methodology

Using a self-reported mailed questionnaire, managers at U.S. printing ink companies were identified using a list of such companies published by *Ink World* magazine (2014). Using methods suggested by Dillman, Smyth and Christian (2014), potential respondents were mailed an introductory letter, followed by a survey package consisting of a questionnaire instrument and postage-paid return envelope. In addition, a link to an Internet-based survey was provided as an alternative method of responding. Steps were taken to assure that all responses were anonymous. Two weeks after the initial survey package was mailed a reminder was sent to non-respondents, and two weeks after the reminder mailing a second complete survey package was sent to those that did not respond. Of the 127 U.S. ink companies identified from the sampling frame, four were no longer in business, and one self-disqualified. In total, 49 companies responded out of the potential 122; a response rate of 40%.

6. Limitations

As a cross-sectional survey, the present study is not designed to uncover the reasons that underlie why ink companies make their particular selections. In addition, as the sampling frame was limited to those ink companies in the *InkWorld* listings, large ink companies with multiple locations were represented by one of their centralized locations. Therefore, a small, single location and perhaps highly specialized ink company has the same weight in the present analysis as did a large organization with numerous locations. Further, this study is limited to those ink companies conducting business in the U.S. In addition, to streamline the questionnaire instrument, variables such as user-defined parametric values inherent in some color differencing methods (e.g.,the lightness to chroma ratio expressed in the DE_{cmc} equation) are not examined.

7. Findings, Data Analysis and Results

The demographic information regarding the respondents is replicated in Table One. If responding companies are divided among those that employ 50 or less versus 51 or more there was a nearly even split.

Table One

Size of Company

Number of employees	*N*	%
< 10	8	16.3
11 – 25	11	22.4
26 – 50	5	10.2
51 – 100	9	18.4
101 – 500	9	18.4
> 500	5	10.2
Don’t Know / Decline	2	4.1

Table two displays results pertaining to user standard operating procedures relevant to instruments and software: instrument geometry, QA software and file format. In these instances, over 80% of users reported utilizing directional 0°/45° or 45°/0° instruments. Four ink companies reported utilizing multi-angle instruments, while three reported using spherical instruments for their standard operating procedure. Turning to software, over 50% of the ink companies responding reported using X-RiteColor Master for colorimetric QA. X-Rite iQC was the second most utilized, with ten reported users and four reported using X-Rite ColorQuality as their standard. The only non-X-Rite software with more than one reported user was Datacolor Tools software, utilized by four of the respondents.

In terms of digital file format, the .mif format dominated with over 40% of users reported utilizing this particular type of file for transferring colorimetric information. This was followed by the .CxF file format with over 16% of users, and the standard file format for Microsoft Excel representing just over 8% of reported users. Of all of the variables examined here, file format resulted in the highest number of “Don’t know,” “Decline to answer,” and questionnaires with no answer selected, representing 35% of the respondents.

Table Two

Instrument and Software Variables

Instrument geometry	*N*	%
0°/45° or 45°/0° directional	40	81.6
Sphere d/8°	3	6.1
Multi-angle / Gonio	4	8.2
None / Decline	2	4.1
Software		
ColorMaster	25	51
iQC	10	20.4
ColorQuality	4	8.2
Tools	3	6.1
Smart	1	2
BASF	1	2
MeasureColor	1	2
Other / None / Decline	4	8.2
File format		
.mif	20	40.8
.CxF (any version)	8	16.3
.xls / .xlsx	4	8.2
None / Don’t Know / Decline	17	34.7

Table Three displays responses regarding illuminant, standard observer and color differencing methods preferred as SOP. The “daylight” illuminants of D50 and D65 dominated as SOPs for respondents, accounting for over 90% of users. Over half of the respondents reported using D50, and over 40% selected D65. In terms of standard observer, the ten degree (1964) standard observer was utilized by over 53% of respondents, with nearly 39% choosing the two degree (1931) standard observer.

Table Three

Colorimetric Variables

Illuminant	N	%
D50	25	51
D65	20	40.8
F2	1	2
None / Don’t Know / Decline	3	6.1
Observer		
10° 1964	26	53.1
2° 1931	19	38.8
None / Don’t Know / Decline	4	8.1
Color Differencing Method		
ΔE_{cmc}	22	44.9
ΔE^*_{ab}	12	24.5
ΔE^*_{00}	8	16.3
ΔE^*_{94}	2	4.1
ΔE^*_{ch}	1	2.0
None / Don’t Know / Decline	4	8.1

When examining color differencing method, ΔE_{cmc} is the most widely used among U.S. ink companies with nearly 45% of respondents indicating this is their choice, while over 24% of ink companies reported using ΔE^*, and ΔE_{00} accounted for just over 16%.

8. Analysis

In an examination of the types of instruments utilized by U.S. ink companies, it is no surprise that directional 0°/45° and 45°/0° instruments are the most widely adopted, as it is likely that densitometry is commonly still utilized in addition to colorimetric data, and 0°/45° or 45°/ 0° geometry is mandated for ANSI status density readings (Brehm, 1999.) Further, such instruments are generally less expensive, easier to use and available with smaller measurement apertures than their spherical and multi-angle counterparts.

The usage of daylight illuminants is also to be expected, although some may find it interesting that the D50 illuminant only represented one-half of the respondents as this illuminant condition is referenced by ISO 13655:2009. Likewise, respondents reported adoption of the two degree (1931) standard observer at 38% versus 53% adopting the ten degree observer. This finding may also be curious to some, as standards committees generally utilize the two degree choice.

The reported preferred use of ΔE_{cmc} as a color differencing equation by many ink companies is of particular note as ΔE_{cmc} is not recognized by standards and specifications committees to the extent of ΔE* and ΔE_{00} (Cheydleur 2013, Warter 2011). The second most widely used color differencing method in this study is ΔE* and ΔE_{00} represents the third most popular choice among respondents. It is noteworthy that the data indicate if the number of ink companies using ΔE* and ΔE_{00} are combined, they still do not equal the nearly 45% of companies adopting ΔE_{cmc} as their SOP.

In the examination of QA software, clearly the X-Rite products enjoy the majority of the market share with U.S. ink companies, three of their software products are adopted by nearly 80% respondents, with X-RiteColor Master representing the most widely utilized. The prevalence of the .mif digital file format may speak to the dominance of X-RiteColor Master as a software choice for QA use as the format been a default selection of Color Master users for many years.

9. Conclusions & Implications

In 1986, Fred Davis published *A technology acceptance model for empirically testing new end-user information systems: theory and results*, where he posited that perceived ease of use and perceived usefulness were antecedents to technology adoption. It is suggested that the technology acceptance model (TAM) is an appropriate lens to view the implications. Clearly, the diversity of colorimetric variables reported as SOPs by U.S. ink companies represents an interesting condition for the printing industry: stakeholders who desire more homogeneity among the colorimetric variables utilized are advised to build the case for the usefulness of selected methods to overcome the inconvenience of the incumbent changing their current SOP. For example, the present study indicates that a large percentage of responding ink companies prefer to utilize DE_{cmc}. This particular tolerancing method is not recognized in ISO12647-2 (2013) which references ΔE^* as a normative parameter with ΔE_{00} as the informative parameter (Cheydleur, 2013). Psychophysical color research that limits comparisons of ΔE^* to ΔE00 could be leaving out wide swaths of the industry as users of DE_{cmc} would be understandably unfazed by such studies. Restated in the view of Davis' TAM, the perceived usefulness of one tolerancing method versus another may not be sufficiently significant to warrant a change.

Similarly, the recent adoption of the file CxF3 file as an ISO standard format (ISO 17972-1: 2015) may not have an immediate impact on what U.S. ink companies continue to use. It is reasonable to conclude that for those utilizing file formats other than CxF3 who are content with their current choice will see little reason to switch unless a case for the superiority of CxF3 can be clearly and empirically established.

10. Future research

Future researchers could adopt a more qualitative approach to print providers and buyers to obtain a richer understanding of the salient factors driving the choices that ink companies make in regard to colorimetric variables. Further, as this research is limited to U.S. ink companies, researchers may choose to examine ink companies outside of the U.S.

Further, the present study potentially builds upon a rich tradition of technology adoption studies conducted since Rogers' *Diffusion of Innovations* was first published in the early 1960's (Rogers, 2003). As such, a point of reference for future researchers in this area is provided. Subsequent researchers may choose to re-examine ink companies in the future to better ascertain the stage of adoption of the variables examined.

Finally, researchers may wish to replicate this study with actual printers to examine which variables such companies choose to select as part of their standard operating procedures: such studies could result in noteworthy comparisons to the present work.

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