A Practical Approach to Measuring and Modelling Paper Fluorescence for Improved Colorimetric Characterisation of Printing Processes

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Abstract

Paper Fluorescent Whitening Agent combined with differences in relative Ultra Violet levels between instrument illuminants, and real world viewing illuminants, can be a significant source of error in characterising a printing process, and hence in the ability to accurately reproduce colored images in print. These errors can be dealt with using bi-spectral measurements, but a simpler approach that significantly reduces paper whitening agent induced errors is possible, while using more practical print characterisation instruments and procedures.

Introduction

The characterisation of printing processes is generally carried out using a simple and well established model of the interaction of an illuminant and colorants laid over a reflective (usually diffusive) support medium, such as paper. (The term "Paper" will be used to represent the substrate medium, whether or not it is actually composed of cellulose). Unlike industrial material characterisation, where the aim might be to make a small number of carefully carried out measurements on a few samples, characterising a printing process for the purposes of making an accurate color profile, usually entails making hundreds, to several thousand color sample measurements for each media/ink combination. These are generally carried out under standard colorimetric viewing conditions, such as the 0/45 or 45/0 conditions described by CIE publication 15.2-1986, with the resulting reflectance values being normalised to that of a perfect isotropic diffuser. Popular and practical instruments currently used for this purpose, are the the GretagMacbeth SpectroScan, Eye-One and iCColor, and the Xrite DTP41. These allow the rapid spectral reflectance measurement of thousands of printed test samples.

Such instruments illuminate a sample of the colorant and paper with a known intensity, and measuring the quantity of light reflected by the sample at each wavelength, and dividing by the illuminant intensity, the reflectance factor at each wavelength of the sample can be measured. This is commonly termed a "Source Independence model". If that sample is then placed in a different illuminant (say a viewing situation), this model assumes that we can simply multiply the intensity of the viewing illuminant by the sample reflectivity at each wavelength, to compute the spectrum of the light emitted by the sample. Given various geometric, colorimetric and color appearance models and assumptions, a numerical estimate of the color appearance can easily be computed.

This model works extremely well in many situations, and most popular instruments and tools intended for the Graphic Arts work within this framework.

One optical property that greatly reduces the accuracy of this model is the presence of any fluorescent substance in either the paper or the colorants, since the characteristic of fluorescence is to absorb light at one wavelength, and reemit it at a longer wavelength. Other studies[1] have noted that in many conventional print process situations, it is not usually the colorants that have significant amounts of fluorescence, but the paper, in the form of Fluorescent Whitening Agent (FWA), and that in many situations FWA is the most significant source of error in characterising how a print sample will appear in a given viewing situation.

Current Approaches to Dealing with FWA, in the Context of Print Profiling

ANSI CGATS.5-1993 Annex B Recommendations

This document doesn't recommend any method to compensate for fluorescence, but recommends some techniques for evaluating the likelihood of the problem, by comparing readings with different illuminant spectra (such as illuminant A and D50 or D65), or comparing readings with and without one or two UV cut-off filters (methods A, B & C respectively). ASTM standard E1247 also describes similar methods for detecting the presence of fluorescent materials.

Matching Paper Characteristics

One use of the colorimetric characterisation of printing materials is for the electronic reproduction of the characteristics of one medium (say a printing press), by another (say an inkjet printer), for the purposes of proofing. If the paper of the proofing system is matched such that the sensitivity and response of FWA it contains is similar to that in the press paper, then the effects of a different measurement and viewing illuminant will be minimised, since both paper will respond in a similar way to any illuminant changes. In practice, it is not often than one has a choice of papers that meet all other criteria (compatibility with the print process, longevity, maximum ink coverage, underlying paper color match etc.), to have the freedom to match FWA levels.

Matching Instrument to Viewing Spectrum

Another method of minimising FWA errors is to try and make sure that the illumination spectrum used by the instrument matches that actually used during viewing. It is for this purpose that some instruments have filters available for their tungsten lamps, that simulate D50 or D65 spectra, or some have less conventional sources of illumination, such as Xenon lamps. ASTM Standard E991 is an example of this approach, and while this seems sound as far as it goes, it is inflexible in the need to know the intended viewing illuminant at measurement time, the need to make multiple different measurements if different viewing illuminants are anticipated, and the difficulty in ensuring that the instrument illuminant spectrum actually resembles the viewing illuminant spectrum. For instance, if the samples are measured using a D65 illuminant, then short of actually viewing the results outdoors, under a Xenon lamp, or under a filtered incandescent lamp, it is difficult to know how likely a D65 viewing illuminant will be encountered. Many practical (so called) D50 and D65 industry viewing booths appear to be based on fluorescent tube lights, which although having broad spectrum phosphors and appropriate white points, don't necessarily have the correct UV to visible spectrum ratio to accurately simulate a daylight or Xenon D65 spectrum in the presence of FWA.

Bispectral Characterisation and Bispectral Model

This approach is the subject of the Gonzalez & Fairchild paper1 and is comprehensive and general, but bispectral instruments are expensive, slow, hard to come by. A bispectral model is also bulky (2d rather than 1d). Bispectral characterisation will handle any sort of fluorescence in the colorants, the paper, or both, but is unnecessarily complete if FWA is the dominant source of fluorescent inaccuracy.

"UV" Filter Legend

Amongst the user (and to some degree) vendor community, there is a widely held belief that the solution to fluorescent whitener affecting color profiles is to use a UV filter fitted instrument. Exactly what the origin of the legend is, is hard to tell. Possibly it is a misinterpretation of the CGATS recommendation, a translation of some of paper whiteness measurement standards into the color profiling world, or possibly in some common situations, the viewing environment is very poor in UV, and adding a UV filter to the tungsten instrument illuminant makes for a better instrument/viewing illuminant match. There seems to be no scientific or practical basis for believing that a UV filter fitted instrument magically makes all FWA induced problems go away.

Another Approach

If FWA effects are to be accounted for in a practical way, then they have to be characterized using readily available instruments, and modelled in a way that makes a real improvement to print characterisation. Some observations aid us in this quest.

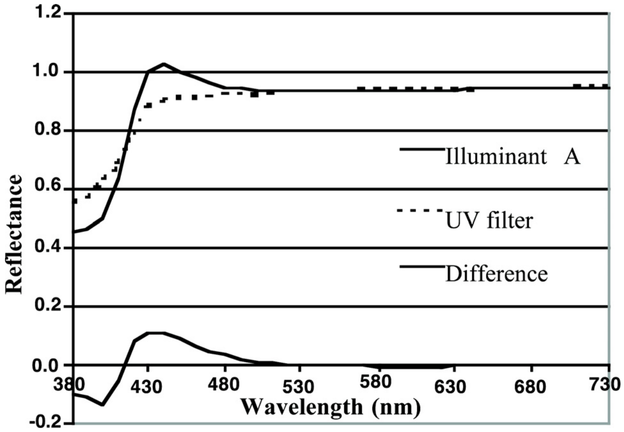

Figure 1. Inkjet paper, spectral reflectance under illuminant A, with and without instrument UV filter.

FWA's have fairly similar characteristics: Although there are many different types of FWA using in paper and other printing media, a survey of some of the papers available indicates that they have broadly similar characteristics. They seem to be stimulated by similar wavelengths, and reemit at similar wavelengths.

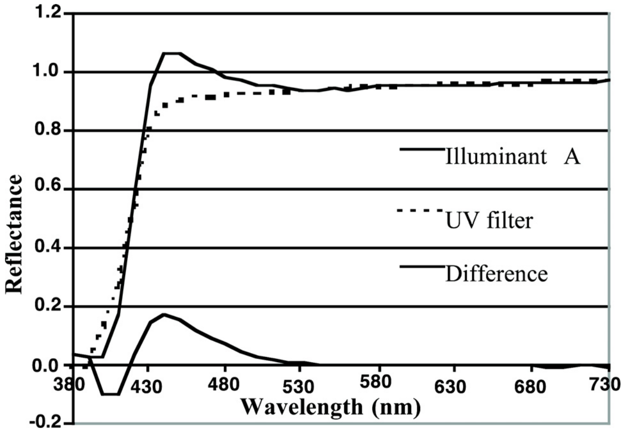

Figure 2. Chemical proofing paper, spectral reflectance under illuminant A, with and without instrument UV filter.

The spectrum of paper with typical "A" or "D65" illuminant shows characteristic "lump" at about 450nm, caused by FWA. Measurement of papers that don't have any

FWA have either flat or gently down sloping reflectance specrtrum as one moves to shorter wavelengths. Measurement of samples using an instrument that can be fitted with a UV filter confirms this supposition.

If both the spectral sensitivity of the FWA at its excitation wavelengths, and the spectral characteristics of emission were known (and intensity ratio or quantum yield also known), then an improved reflectance model that takes account of FWA effects can be developed.

Fluorescent Whitener Reflectance Model

Based on the current simple model, and some of the ideas in the paper by Emmel & Hersch[2], and on the constraint that only parameters that can be measured of reasonably estimated can be included, the following model was developed:

The normal spectral reflectance values measured in a paper can be decomposed into a simplified model in which the incident light is filtered by the colorant, is reflected by the paper, filtered again by the colorant, and then transmitted back to the observer. This is analogous to the principles of Beer's Law, but simplified to the context here of a standard reflectance measurement. The reflectance of the paper is typically known, because the plain paper is read in the series of measurements used to characterise a device.

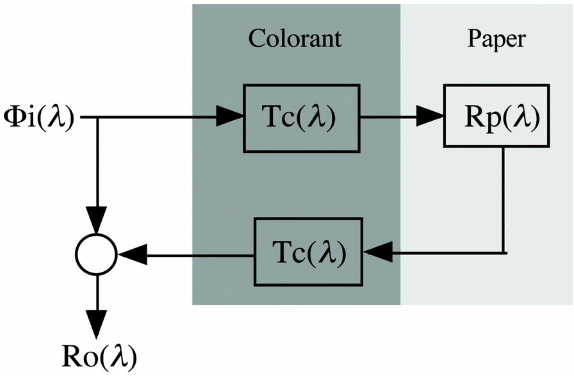

Figure 3.

$Ro(\lambda)$	Overall Reflectance Factor
$\Phi i(\lambda)$	Illuminant flux
$Tc(\lambda)$	Colorant layer transmittance factor
$Rp(\lambda)$	Paper reflectance

$$Ro(\lambda) = \frac{\Phi i(\lambda)\cdot Tc(\lambda)\cdot Rp(\lambda)\cdot Tc(\lambda)}{\Phi i(\lambda)} \qquad (1)$$

This model doesn't take into account Fresnel, pigment or scattering effects, but since in the final model FWA will be compensated for as a difference to the overall reflectance, this simplifying assumptions are not of any great significance. This model also assumes a thin film colorant intensity control approach rather than screened control, but in practice this difference isn't very significant in the final result either.

The basic model allowing for fluorescence in the paper, is that as well as the light reflected from the paper substrate, there will be an additional light contribution from the FWA.

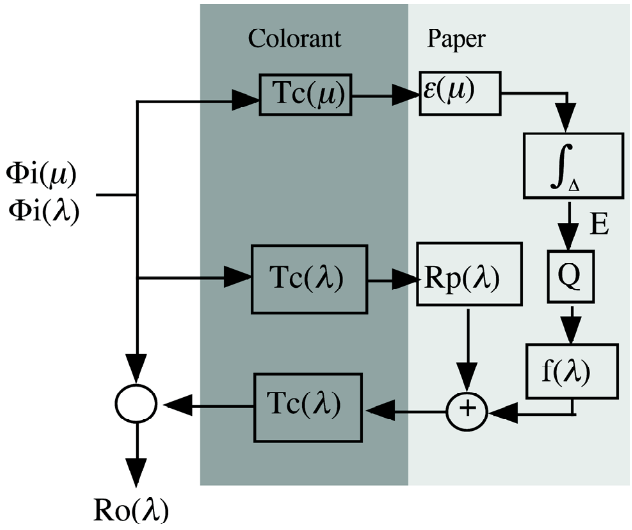

Figure 4

The overall level of light emitted by the FWA is assumed to depend on the integrated level of light received over the FWA's excitation spectrum. This integral will depend on the illumination spectrum as well as the filtering effects of any colorant on the excitation spectrum.

$\varepsilon(\mu)$	FWA normalised excitation spectrum
E	Overall FWA excitation level
Q	Quantum yield factor
Δ	Excitation Spectrum range, typ. 300-600nm

$$E = \int_{\Delta} \varepsilon(\mu)\cdot \Phi i(\mu)\cdot Tc(\mu) \qquad (2)$$

Adding in the FWA emission, the model for overall reflectance at a given wavelength becomes:

$f(\lambda)$	Fluorescent Emission level at unity excitation.

$$Ro(\lambda) = \frac{\left(\Phi i(\lambda)\cdot Tc(\lambda)\cdot Rp(\lambda) + E\cdot Q\cdot f(\lambda)\right)\cdot Tc(\lambda)}{\Phi i(\lambda)} \qquad (3)$$

Note that if we want to compute the $Tc\,(\lambda)$ from reflectance readings, under conditions in which fluorescence is present, that equation (3) must be used, rather than equation (1).

Parameter Measurement and Estimation

It is assumed that the illuminant spectrum used by the instrument is known and well characterised. It is also assumed that the illuminant under which the sample is to be viewed is also known and well characterised.

The paper reflectance (including any FWA contribution) can be measured by a conventional spectrometer, as can the overall reflectance of colorant on the paper.

The two unknowns are the FWA excitation sensitivity spectrum, and the FWA emission spectrum.

Without using a bi-spectral instrument of some description, there does not seem to be any means to measure or estimate the FWA excitation sensitivity spectrum. To solve this problem, the assumption is made that this spectrum is similar for most FWA's, and that a representative spectrum will be sufficient. The raw data from Gonzalez & Fairchild1 has been made available, and it contains bispectral data for Xerox White Paper for Inkjets, and this was used as the basis for the following results. If a bispectral instrument was available, it would be interesting to survey a number of papers containing FWA, and obtain a better founded idea of the range of excitation sensitivity spectra in the field, as well as obtaining a more representative mean.

The readings taken with the Spectrolino point towards a way of measuring the FWA emission spectrum. If the reading using the UV filter are subtracted from those without, a good estimate of the emission spectrum is obtained. While this is a perfectly practical way to obtain this information, it is mechanically inconvenient to have to take two sets of readings, and many popular instruments do not allow a UV filter to be switched in and out by the user. An instrument that had a filter that could be switched in and out under software control would be more convenient, or one that had an illuminant that could be switched between two different, known levels of UV intensity.

As a useful alternative to needing an instrument that has a user selectable UV filter, the following observation can be used:

The general shape of the reflectance spectrum of the paper without FWA is nearly flat, or slopes slightly down towards the shorter wavelengths. By using the spectral reflectance readings at longer wavelengths that FWA is expected to emit, it is possible to estimate by simple extrapolation what the FWA free paper spectrum will look like. Figure 5 and equations 6, 7, 8 & 9 detail the particular heuristic derived from this idea, and used to produce the results in table 1, and figures 6 and 7. The heuristics were determined by surveying a series of papers containing FWA available to the author, and adjusting the approach to give results consistent with UV filtered measurements, and consistent in reducing the effects of FWA under the verification conditions.

A complicating factor in some whitened papers, is the addition of shading agents, which reduce reflectance in the middle wavelengths. This influenced the choice of wavelengths used in the heuristics. A review of paper brightness available on the web[3] was very useful in understanding the approaches taken in the paper industry with regard to increasing paper whiteness, as well as some approaches taken to separate out underlying paper characteristic from the FWA effects.

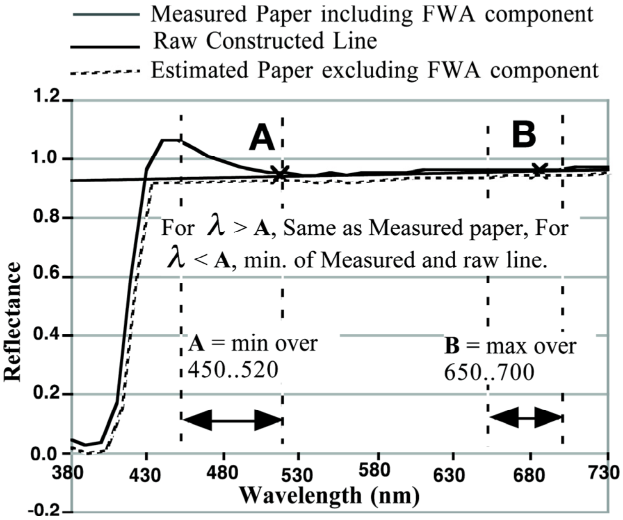

Figure 5. Construction of estimated paper reflectance with no FWA contribution.

Conceivable, these heuristics could be further refined, perhaps dealing more robustly with a wider variety of papers and FWA types, and perhaps more accurately accounting for the typical “roll off” in reflectivity at shorter wavelengths, and the extra absorption due to the FWA itself.

Note that a limitation of this technique is that it assumes a “typical” characteristic of “white” paper, and papers with a deliberate tint, are probably not suitable for use with this particular heuristic. Since deliberately tinted paper stock is not usually used for high quality color reproduction, this is probably not a major limitation in practice.

By using this technique, it is only necessary to have spectral reflectance readings from an instrument with a reasonable level of known UV in its illuminant, to be able to make a useful estimate of the FWA emission spectrum.

What follows then, is a step by step description of the algorithm based on these principles, use to compensate print sample spectral reflectance measurements for the effects of FWA under a target illuminant different to the measurement illuminant. In this description, identifiers are used that have a close correspondence to the relevant C code implementation, for ease of comparison with the published code.

Initialisation of FWA Compensation for a Particular Paper Stock, Instrument Readings and Target Illuminant:

Inputs to initialisation:

Iinst(λ)	Instrument illuminant spectrum
Itarg(λ)	Target viewing illuminant spectrum
Rwhite(λ)	The reflectance spectrum of the paper, including FWA
Sstim(λ)	FWA excitation sensitivity spectrum estimate
Λ	Visual Spectrum, range typ, 380-800 nm

Initialisation outputs:

uRwhite(λ)	The estimated reflectance spectrum of the paper, minus FWA
Iemit(λ)	The estimated FWA emission of the paper
nIinst(λ)	Area normalised instrument spectrum
nItarg(λ)	Area normalised target viewing illuminant spectrum
Sm	Integrated excitation level of UV causing Iemit(λ)

Initialisation intermediate variables:

ar	A point reflectance of paper
aw	A point wavelength of paper
bri	Initial B point reflectance of paper
bwi	Initial B point wavelength of paper
br	B point reflectance of paper
bw	B point wavelength of paper
Rl(λ)	AB line reflectance

Compute the spectral area normalised instrument illuminant spectrum

$$\mathrm{nIinst}(\lambda) = \frac{\mathrm{Iinst}(\lambda)}{\int_{\Lambda} \mathrm{Iinst}(\lambda)} \qquad (4)$$

Compute the spectral area normalised target illuminant spectrum

$$\mathrm{nItarg}(\lambda) = \frac{\mathrm{Itarg}(\lambda)}{\int_{\Lambda} \mathrm{Itarg}(\lambda)} \qquad (5)$$

Estimate the white paper spectrum without FWA using the following procedure:

Find the point "A" that has the lowest reflectance between 450 and 520 nm, and note its reflectance and wavelength

$$\begin{aligned} &\mathrm{Ar} = \min\big(\mathrm{Rwhite}(\lambda = 450\ldots520)\big) \\ &\mathrm{Aw} \;=\; \lambda \text{ at Ar} \end{aligned} \qquad (6)$$

Find the point "B" that has the highest reflectance between 650 and 700 nm, and note its reflectance and wavelength

$$\begin{aligned} &\mathrm{Bri} = \max\big(\mathrm{Rwhite}(\lambda = 650\ldots700)\big) \\ &\mathrm{Bwi} \;=\; \lambda \text{ at Bri} \end{aligned} \qquad (7)$$

Make sure that the line joining A and B is flat, or slopes down towards the smaller wavelengths (towards A)

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if $\mathrm{Bri} < \mathrm{Ar}$
    $\mathrm{Br} = \mathrm{Ar}$
    $\mathrm{Bw} = \mathrm{Aw}$
else
    $\mathrm{Br} = \mathrm{Bri}$
    $\mathrm{Bw} = \mathrm{Awi}$                (8)
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We now want to separate the paper spectrum into the estimated underlying paper reflectance, and the emission spectrum of the FWA under the conditions it was measured. Note that the emission spectrum is an absolute emission spectrum, that is assumed to be proportional to the integrated excitation being applied.

$\mathrm{Rl}(\lambda)$	Reflectance of the line passing through points A and B.

$$\mathrm{uRwhite}(\lambda) = \min\big(\mathrm{Rl}(\lambda),\ \mathrm{Rwhite}(\lambda)\big) \qquad (9)$$

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For each $\lambda$ band
  if $\lambda < \mathrm{Aw}$ and $\mathrm{uRwhite}(\lambda) < \mathrm{Rwhite}(\lambda)$ then
    $\mathrm{Iemit}(\lambda) = \big(\mathrm{Rwhite}(\lambda) - \mathrm{uRwhite}(\lambda)\big) \cdot \mathrm{nIinst}(\lambda)$
  else
    $\mathrm{Iemit}(\lambda) = 0$                (10)
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Compute the integrated UV excitation that emission estimated above.

$$\mathrm{Sm} = \int_{\Delta} \mathrm{nIinst}(\lambda) \cdot \mathrm{Sstim}(\lambda) \qquad (11)$$

Applying FWA Compensation to Estimate Paper Reflectance Values Under a Different Illuminant:

Inputs to compensation:

Rin(λ)	Input (uncorrected) reflectance spectrum

Results of compensation:

Rout(λ)	Output (corrected) reflectance spectrum

Intermediate computation values:

Emci	Estimated FWA excitation factor of instrument illumination
Emct	Estimated FWA excitation factor of target illumination
Kci(λ)	Estimated FWA component for sample under instrument illumination
Kct(λ)	Estimated FWA component for sample under target illumination
Fc(λ)	Estimated filter value of colorant

First we need to estimate the integrated UV excitation level for this amount of colorant, for both the instrument illumination, and the target illumination. We are assuming that overlap of the excitation and emission spectrum is of little consequence, but if this was of importance, it could be accounted for using an iterative approach to computing the colorants effects on the UV excitation levels.

$$\mathrm{Emci} = \int_{\Delta} \mathrm{Sstim}(\lambda) \cdot \mathrm{nIinst}(\lambda) \cdot \sqrt{\frac{\mathrm{Rin}(\lambda)}{\mathrm{uRwhite}(\lambda)}} \tag{12}$$

$$\mathrm{Emct} = \int_{\Delta} \mathrm{Sstim}(\lambda) \cdot \mathrm{nItarg}(\lambda) \cdot \sqrt{\frac{\mathrm{Rin}(\lambda)}{\mathrm{uRwhite}(\lambda)}} \tag{13}$$

We want to compute the underlying filtering effect of the colorant over the paper for this sample. We know the samples reflectance under the instrument illuminant is nIinst(λ), and we know how that is computed using our paper reflectance model equation (3).

Rearranging (3) gives us the following quadratic to solve:

$$\mathrm{nIinst}(\lambda) \cdot \mathrm{Rin}(\lambda) = \mathrm{nIinst}(\lambda) \cdot \mathrm{uRwhite}(\lambda) \cdot \mathrm{Fc}(\lambda)^2 + \mathrm{Kci}(\lambda) \cdot \mathrm{Fc}(\lambda) \tag{14}$$

which is solved in the usual way, taking the positive (physically realisable) solution.

Equation (3) is then applied to compute the expected reflectance under the target illuminant:

FWA emission component for instrument:

$$\mathrm{Kc}(\lambda) = \frac{\mathrm{Emci}}{\mathrm{Sm}} \cdot \mathrm{Iemit}(\lambda) \tag{15}$$

FWA emission component for target:

$$\mathrm{Kct}(\lambda) = \frac{\mathrm{Emct}}{\mathrm{Sm}} \cdot \mathrm{Iemit}(\lambda) \tag{16}$$

$$\mathrm{Fc}(\lambda) = \frac{-\mathrm{Kci}(\lambda) + \sqrt{\mathrm{Kci}(\lambda)^2 + 4 \cdot \mathrm{nIinst}(\lambda)^2 \cdot \mathrm{uRwhite}(\lambda) \cdot \mathrm{Rin}(\lambda)}}{2 \cdot \mathrm{nIinst}(\lambda) \cdot \mathrm{uRwhite}(\lambda)} \tag{17}$$

FWA compensated reflectance spectrum:

$$\mathrm{Rout}(\lambda) = \frac{\left(\mathrm{nItarg}(\lambda) \cdot \mathrm{Fc}(\lambda) \cdot \mathrm{uRwhite}(\lambda) + \mathrm{Kct}(\lambda)\right) \cdot \mathrm{Fc}(\lambda)}{\mathrm{nItarg}(\lambda)} \tag{18}$$

Verification

As a means of verifying the accuracy of FWA compensation, the following series of measurements were performed. Using a Gretag Macbeth Spectrolino spectrometer, which natively uses a tungsten illuminant in its measurements (ie. A spectrum), and can also be fitted with an optical filter that simulates the D65 spectrum, then it is possible to make cross comparison measurements, by measuring a series of samples under A and D65 illuminants, and comparing the actual measurement with the simulated one for the other illuminant. It is also then possible to see how much measurement inaccuracy is corrected using the described FWA compensation technique.

The tests were conducted using just the Black and Yellow colorants, since these are the only two commonly used in printing, that interact significantly with the U.V. and FWA emitted components.

In most cases the L*a*b* error is reduced to less than 1 Delta E, from a worst case of 5. In some cases the compensation worsens the result, but the error is still less than 1 delta E. Figures 6 and 7 are two example spectral plots from the table.

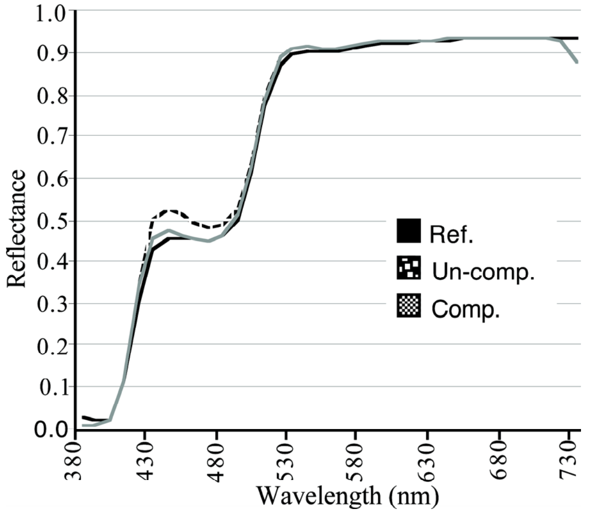

Figure 6. Ch. Proof, 30% Y, Target A, Measured D65

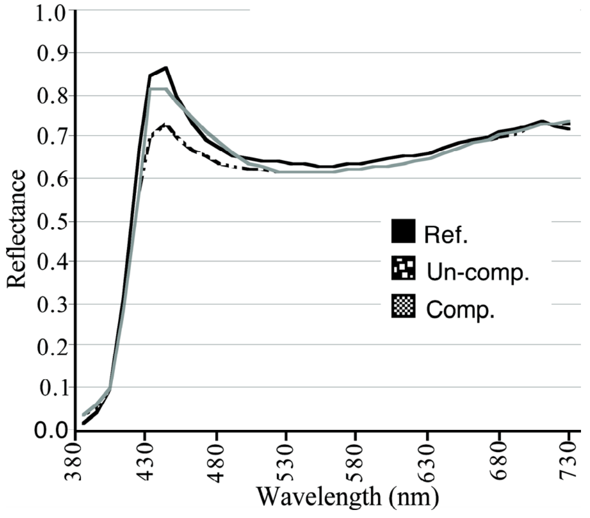

Figure 7. Inkjet, 30% K, Target D65, Measured A

Note that there is some discrepancy in the longer wavelengths between the reflectance measured under A and D65 illuminant. This raises some suspicion that the instrument itself is not calibrating as well as it should between the two different illuminants. The calculations were based on the instrument filtered spectrum being exactly D65, whereas a filtered tungsten spectrum could be expected to deviate from this assumption to some degree, possibly making the results worse than can be expected when the actual illuminant spectrum are known.

Table 1. Verification Results

Medium	Target Illuminant	Measurement Illuminant	Patch	No FWA comp. Delta E	FWA Comp. Delta E	Improvement
Ch. Proof	A	D65	30% Y	2.963991	0.682259	2.281732
Ch. Proof	A	D65	60% Y	2.484987	0.635285	1.849702
Ch. Proof	A	D65	90% Y	2.501057	0.744927	1.75613
Ch. Proof	A	D65	30% K	2.727183	0.565248	2.161935
Ch. Proof	A	D65	60% K	2.218406	0.748971	1.469435
Ch. Proof	A	D65	90% K	2.793648	0.761264	2.032384
Ch. Proof	D65	A	30% Y	4.877198	0.438131	4.439067
Ch. Proof	D65	A	60% Y	4.09463	0.942075	3.152554
Ch. Proof	D65	A	90% Y	4.2407	0.60107	3.639629
Ch. Proof	D65	A	30% K	4.893272	0.814928	4.078344
Ch. Proof	D65	A	60% K	4.092725	0.714466	3.378258
Ch. Proof	D65	A	90% K	5.098779	2.075015	3.023764
Inkjet	A	D65	30% Y	2.082687	0.4358	1.646888
Inkjet	A	D65	60% Y	1.598877	0.223749	1.375128
Inkjet	A	D65	90% Y	0.376801	0.120338	0.256463
Inkjet	A	D65	30% K	1.902921	0.455543	1.447378
Inkjet	A	D65	60% K	1.360402	0.457212	0.903189
Inkjet	A	D65	90% K	0.168456	0.686763	-0.51830
Inkjet	D65	A	30% Y	3.871041	0.974465	2.896575
Inkjet	D65	A	60% Y	2.778405	0.352496	2.425909
Inkjet	D65	A	90% Y	0.570258	0.497214	0.073044
Inkjet	D65	A	30% K	3.657021	0.831099	2.825921
Inkjet	D65	A	60% K	2.605088	0.435228	2.16986
Inkjet	D65	A	90% K	0.271215	1.019598	-0.74838

For this FWA compensation technique to work well, it is important to note that the instrument illumination and target illumination spectrum need to be characterised down to the UV wavelengths (about 300nm). Currently, many popular instruments only measure the visible wavelengths (down to 380 to 400nm), and are therefore not very useful as sources of illuminant spectrum for use with this technique. This is perhaps due to the technical difficulties of creating cheap instruments that cover more than a 2:1 range of wavelengths, as well as the lack of need for measurements beyond 380nm, given the conventional Source Independence model. If the type of technique described in this paper are more widely adopted, then perhaps some of the instrument makers may see fit to extend the measurement range to 300nm. Currently, the options are to use illuminant spectrum that are documented to 300nm (as are the standard sources, such as Illuminant A, D50, D65 etc.), procure an instrument capable of measuring to 300nm for the target illuminant characterisation, or to extrapolate from the measured values bellow 380nm. Fortunately, characterising the target illuminant is not something that generally needs to be done often, permitting a greater level of effort to be applied in establish suitable data.

Conclusion

A practical and convenient technique has been described for measuring and modelling the effects of Fluorescent Whitener Additive in printing system characterisation, when the final viewing illuminant is known. This technique is capable of reducing whitener induced measurement errors from typically 4 delta E to less than 1.

The results from this paper are embodied in the open source, research color calibration and correction package Argyll (http://web.access.net.au/argyll/), in the file xicc/xspect.c, licensed under the GNU licence.

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Biography

Graeme Gill is the Research and Development Manager of Colorbus Australia, which develops colour printer controllers for digital printing and colour proofing applications. He received a B.E. degree in Electronic Engineering in 1984 from the Royal Melbourne Institute of Technology. Prior to joining Colorbus, he worked for Labtam Australia enhancing the X11 server software in their range of color X terminals, as well as having an extensive background in digital circuit design, and a long interest in the computer graphics field. Mr Gill is a member of the IEEE, ACM and IS&T, and is currently the treasurer of the local Melbourne SIGGRAPH chapter.