Process Control for Metallic Color Printing Using Commonly Available Metrology in the Graphic Arts

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Keywords

metallic ink, process control, densitometry, colorimetry

Abstract

There is a need for consistent metallic color printing at the longest possible ink mileage while achieving the demand for visual appeal. This paper describes an initial exploration of process control of metallic color using commonly available metrology in the graphic arts. In this methodology, spectral reflectance data across the visible region are measured using 0/45 geometry with and without a polarized filter. Spectral reflectance values are, then, used to derive densitometric (Status T and Status I) and colorimetric (CIELAB and CIELCh) values. They represent potential process control parameters for metallic color printing.

Two sets of metallic color samples were measured. One set represents six different formulations of bronze metallic colors at two different ink film thicknesses (IFT). The other set represent a single silver sample with six IFT variations. To determine which one of the color measurement parameters provides the most sensitive response to ink film thickness (IFT) variation among metallic samples, correlations between IFT, representing the independent variable, and densitometric and colorimetric parameters, representing dependent variables, were investigated.

It was concluded that polarized readings are more sensitive to IFT changes than unpolarized readings for both metallic colors, both for Status T and Status I densities, as well as lightness (L*). Status I density readings of the blue filter are more sensitive than Status T density readings for bronze metallic colors. For the silver metallic colors, there is no difference between the two status densities, since the visual filter is the same for both. The chromatic dimension for bronze metallic colors, expressed either in chroma (C*) or a* and b*, has a more sensitive response to IFT changes without a polarized filter.

Introduction

Metallic colors are used in the graphic arts to provide a higher visual appeal to the printed product. The visual appeal is achieved due to the strong reflection of light from the metallic flakes that are dispersed in the vehicle of the ink and are laid down on a predominantly horizontal orientation, behaving like mirror-like surfaces that have a strong specular reflection.

Metallic colors contain copper or aluminum powder that result in a gold or silver metallic effect respectively. Alloys of copper and zinc, with increasing zinc content, produce different hues of gold that range from yellowish to reddish.

The goal of the printer is to achieve consistent color reproduction with excellent mileage that assures the demanded visual appeal with the least amount of metallic color laid on the substrate. The importance of printing with the appropriate amount of ink lies on the high cost of metallic colors and on printability and runability issues that are related to the behavior of the metallic ink on the press.

Literature review

The appearance of metallic colors is largely a function of their spectral reflectance in combination with a wide range of surface effects. This combination is difficult to characterize and measure (CGATS/SC3 N 447, 2001). Surface effects have primarily a specular reflection, and the spectral reflectance involves mostly the scattered light that is diffusely reflected from the ink film. The diffuse reflection is caused by the light that is scattered in the ink film and is diffused at the edges of the flakes. Thus, the smaller the diameter of the flakes, the higher the diffuse reflection and the higher the density reading at 0/45 geometry.

However, the thickness of the ink film that achieves the desired appearance cannot be measured precisely from commonly available instruments that utilize 0/45 or 45/0 measuring geometry, due to the strong specular reflection of the light. Previous studies (Rosenberg, 2001; Mannig and Verderber, 2002) explain that the reflection of light from the metallic flakes is stronger than the "ideal white diffuser" that is used as the reference for color assessment. Densitometry compares the light that is reflected from the unprinted surface (Io) to the light that is reflected from the printed surface (I1), by means of D = log10 Io/I1. Since the reflection of light from the metallic flakes is higher than the reflectance of the unprinted surface, the density reading of the white point might be drastically reduced. Furthermore, CGATS/SC3 N447 (2001) notes that the metallic appearance is not measured precisely by 0/45 or 45/0 geometry because the particular geometry does not correspond to the exact angle of specular reflection.

Metallic appearance, however, is not the focus of this paper, and as such Rosenberg's study (2001) which discusses this topic is of secondary importance. Likewise for Matthew Adby's paper (2003) that describes metallic luster measured by means of a sphere spectrophotometer. Metallic luster is defined by Gary Field (1998) as the ratio of specularly reflected light to the diffusely reflected light from the same surface. The study of Mannig and Verderber (2002) discusses the reduction of the effect of the specular reflectance by utilization of polarized filters, having more relevance to process control applications. The present paper provides additional insight towards this direction.

Polarized filters block the scattered light that is reflected from the metallic flakes. In this manner, polarized filters significantly reduce the amount of reflection due to the metallic mirror-like surface and increase the density reading, allowing a more accurate measurement of ink film thickness (IFT) (Sigg, 2005).

This study further proposes the use of narrowband Status I density (20 nm bandwidth), instead of the wideband Status T density (100 nm bandwidth) that is standardized in the United States. Status T densities were defined to match as closely as possible the spectral products historically used in evaluating original artwork meant to be color separated (ISO/CD 5-3, 2006). To achieve this visual match it was important to 'sample' a wider range of wavelengths. However, this decreased the sensitivity to the response at the peak wavelength of the filters. Status I spectral density is applicable to the evaluation of graphic arts materials such as process ink on paper. Status I spectral densities are derived from narrowband filters that amplify the spectral reflectance at the peak wavelength of each filter, and as such provide higher densities and higher sensitivity to IFT variations (Kipphan, 2001).

Metallic colors, however, do not peak on the wavelength where each filter is meant to measure. Bronze metallic colors, having a primarily yellow hue, shall be measured by the blue filter (dB). Silver metallic colors have a grey hue, and they shall be measured by the visual filter (dV). However, there is no difference in the visual filter between Status T and Status I densities. The visual filter is calculated for both status densities by formula dV=-log10(Y/100).

A final remark is that the calculation of L* is also based on Y. This would mean that the response of both dV and L* would be identical, if not for the logarithmic nature of dV, that reduces the sensitivity for spectral products of high reflectivity.

Objective

The objective of this paper is to evaluate the commonly available metrology used for process control of metallic inks. The focus is on metrology for process control of metallic inks using 0/45 geometry. The spectral reflectance of a number of different formulations of metallic colors will be measured both with and without a polarized filter. The spectral reflectance data will be converted to colorimetric values (CIELAB and CIELCh) and densitometric values, using both Status T and Status I densities.

The limitations of this paper is that the specification of metallic inks will not be addressed, as it more closely related to their appearance attributes. Moreover, the integrating sphere geometry and goniospectrophotometry will not be addressed, as they are not commonly available in printing plants.

Methodology

The measuring instrument used in this experiment will be the GretagMacbeth Spectrolino Spectroscan spectrophotometer, measuring the spectrum from 380 to 730 nm at 10 nm intervals, and using a 0/45 geometry. The measurements will be done both with and without a polarized filter.

The spectral data will be converted to Status T and Status I densities, utilizing a Microsoft Excel spreadsheet that was provided by Franz Sigg, Research Associate at RIT. The colorimetric coordinates will be specified in CIELAB and CIELCh, which will be exported from GretagMacbeth's MeasureTool 5.0.1. The illuminant used will be D50, and the standard observer will be 10-degrees, because it is more appropriate for uniform colored areas larger than a 4-degree field of view.

The metallic color samples were created by Eckart America L.P. using an IGT printability tester. Six bronze metallic colors with different formulations were provided and measured. Each bronze sample came at two ink film thicknesses (IFTs), one low and one high. Additionally, Eckart created one silver metallic color at six different IFTs.

After the measurements and the computations, the data were analyzed and evaluated by means of graphical analysis, with the focus to relate the measurement responses with relation to IFT changes.

Results

The results for the bronze metallic colors and the silver metallic colors follow.

Bronze metallic colors

The spectral reflectance of the low- and high-density bronze metallic color samples was measured both with polarized and unpolarized filter. Figure 1 displays the spectral reflectance curve of one of the samples. The response of the rest of the samples was identical. The orange lines represent the low-density readings, and the green lines the high-density readings. The squares and circles stand for the unpolarized and polarized readings respectively. It can be seen that the polarized filter results in lower reflectance (and consequently higher density) for both IFTs. Additionally, at the lower end of the spectrum, where the blue density filter is used, the difference between the low- and high - density for the polarized readings is larger than from the unpolarized-density difference, meaning that polarized filter readings are more sensitive to changes in IFT.

An additional observation is that the polarized filters have flat responses for wavelengths higher than 500nm. This is caused by the exclusion of the specular reflections from the metallic surface that would have provided information about the color appearance of the sample. In comparison, the unpolarized readings are a not such a flat curve.

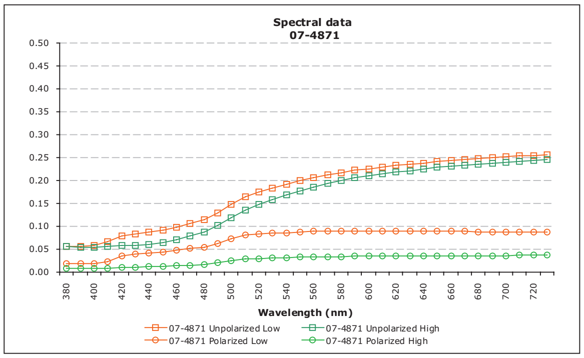


Figure 1: *The spectral power distribution of one bronze metallic sample.*

The spectral measurements were then converted to density readings. Figure 2 displays another bronze metallic sample and it additionally includes the responses of the Status I and Status T densities for the blue filter. It can be seen that Status I filter samples the spectral reflectance over a narrower range; and it has a higher peak that translates into an amplified and thus higher and more sensitive density reading. On the other hand, Status T density has a lower peak that spreads over a broader range of the spectrum.

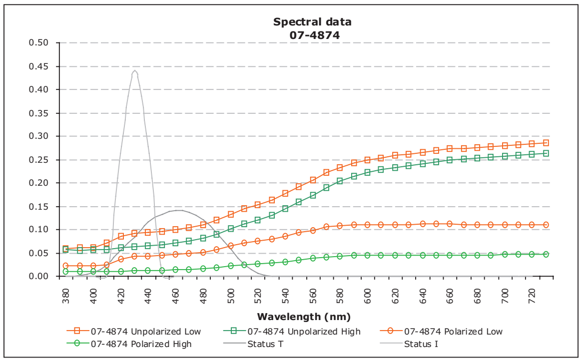


Figure 2: *Status T and Status I density spectral reflectance responses for a bronze metallic color sample.*

Figure 3 analyzes the two different status density responses of the same bronze color sample. The left column displays Status T density and the right Status I. It can be seen that Status I densities have higher readings. Also, the polarized filters have higher readings for both status densities (circles). More analytically, the density difference between the polarized and unpolarized readings is slightly higher for Status I (1.815-1.110=0.705 for Status T and 1.95-1.23=0.72 for Status I). This is observed in all the samples and illustrates the higher sensitivity to IFT differences of Status I density.

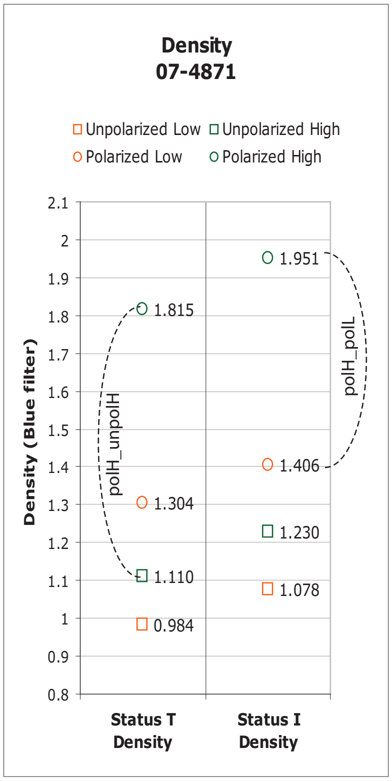


Figure 3: *Status T and Status I density responses for a bronze metallic color sample.*

Next, the colorimetric sensitivity of polarized and unpolarized readings for bronze metallic colors is discussed. Figure 4 displays an a*b* plot of the same sample. It can be observed that unpolarized readings have a larger chromatic difference, since the square spots are further away from each other than the circle spots. This means that unpolarized filters are to a degree more sensitive in describing the chromatic variation due to IFT, even if they fail to be as accurate with regard to lightness (L*).

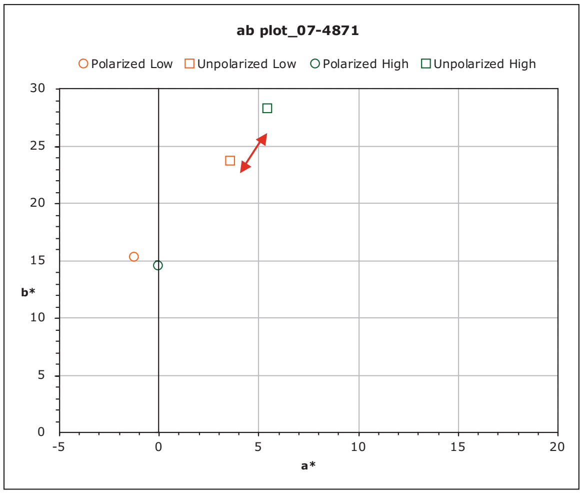


Figure 4: *a*b* plot of bronze metallic color.*

The analysis proceeds with the discussion of chroma (C*) and lightness (L*) in CIELCh for the same bronze metallic sample. In Figures 5-7 in the close up of L* it is observed that the L* difference of the polarized readings (circles) for low and high density is larger than the L* difference of the unpolarized readings. On the contrary, chroma (C*) displays a larger difference in the case of the unpolarized readings, which are more sensitive to IFT differences.

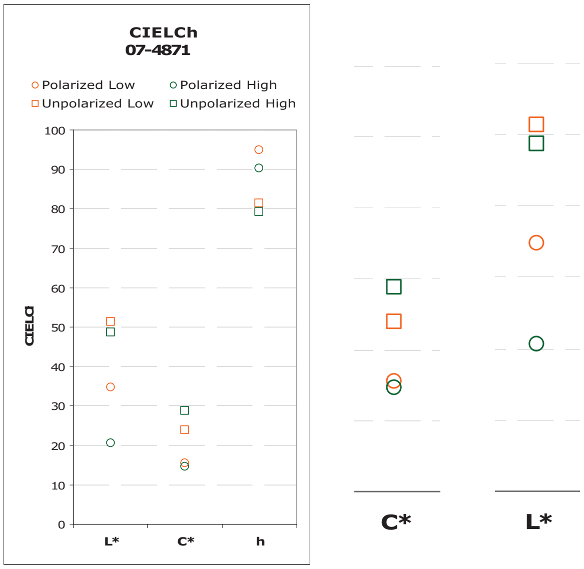


Figure 5-7: *L* and C* analysis of a bronze metallic color sample.*

Table 1 displays the density difference for the blue filter readings between all the low-density and the high-density samples. It can be seen that for all the samples the Status I polarized density reading is consistently higher. Second most sensitive response is with the polarized reading but with Status T density. Unpolarized readings are less

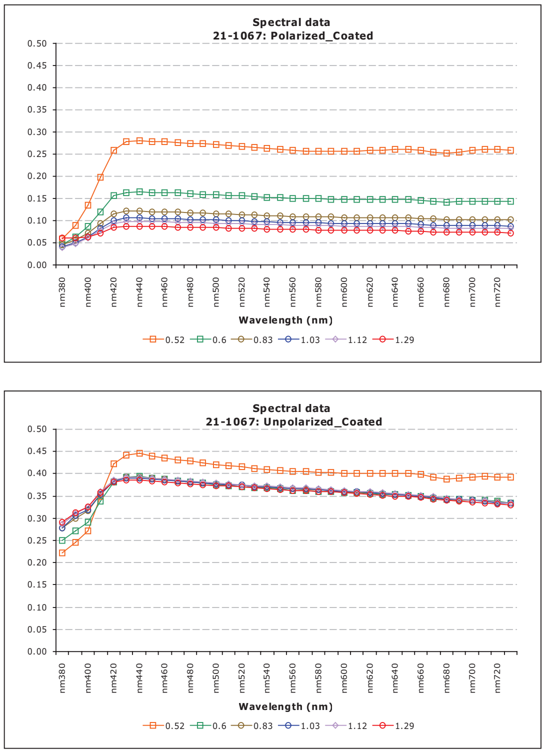
Table 1: *Density difference of the blue filter for low- and high-density bronze metallic color samples.*

Density different high - low (blue filter)			
		Status T	**Status I**
07-4871	Unpolarized	0.126	0.151
07-4871	Polarized	0.511	0.545
07-4872	Unpolarized	0.139	0.167
07-4872	Polarized	0.507	0.534
07-4873	Unpolarized	0.136	0.157
07-4873	Polarized	0.525	0.553
07-4874	Unpolarized	0.140	0.161
07-4874	Polarized	0.520	0.550
07-4875	Unpolarized	0.110	0.130
07-4875	Polarized	0.543	0.554
99-1455	Unpolarized	0.141	0.158
99-1455	Polarized	0.447	0.461
Average	**Unpolarized**	**0.132**	**0.154**
Average	**Polarized**	**0.509**	**0.533**

sensitive, but still Status I densities have a higher sensitivity than Status I densities.

Silver metallic colors

The analysis starts with the display of the spectral reflectance for the silver metallic of 6 different inks that vary from 0.52 dV to 1.29 dV. Figures 8 and 9 display the spectral reflectances as read with a polarized (Figure 8) and an unpolarized filter (Figure 9). It can be seen that the responses are overall flat, due to the grey –achromatic- appearance of the silver samples. A second observation is that the polarized readings show more differences between the IFTs. Finally, the unpolarized readings have a higher reflectance due to the scattering of the light.



Figures 8 and 9: *Spectral reflectance of silver metallic colors with a polarized (top) and an unpolarized filter (bottom).*

As noted earlier, due to the grey appearance of the silver metallic colors, the visual density will be used, which is the same both for Status T and Status I densities. It can be seen in Figure 10 that unpolarized readings have a flat response and are not able to distinguish between the different IFTs. On the other hand, polarized readings range from a density of approximately 0.60 to a density of 1.10, being sensitive enough to distinguish between the different IFTs.

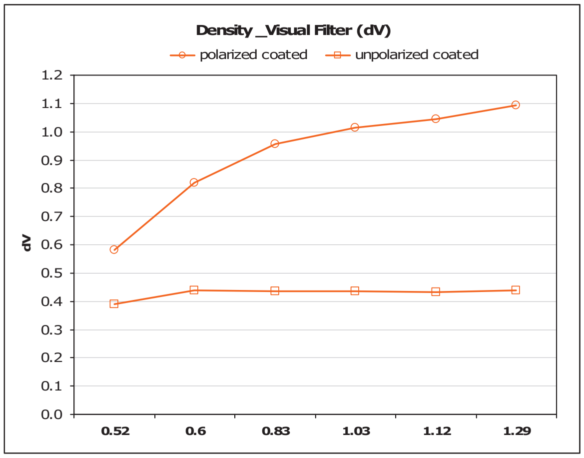


Figure 10: *Density reading of the visual filter for polarized and unpolarized metallic samples of varying IFT.*

Next, the colorimetric coordinate of lightness (L*) is examined. It is seen in Figure 11 that polarized L* readings provide a sensitive response for monitoring IFT variations for process control. Specifically, the difference in L* for polarized samples ranges of 25.0 DeltaL*, whereas for unpolarized the difference is only 10.0 DeltaL*.

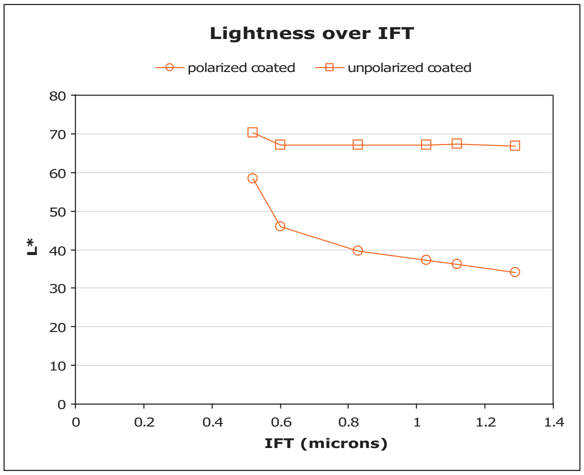


Figure 11: *The lightness (L*) response of polarized and unpolarized readings of silver metallic color samples of different IFTs.*

Finally, Figure 12 displays the chromatic difference for silver metallic colors. It is observed that there is no important C* difference between polarized and unpolarized readings, and moreover the C* reading is low, about 2.00 C*. This indicates that there is no hue difference as well between unpolarized and unpolarized readings, as that would be insignificant due to the strong achromatic nature of the samples.

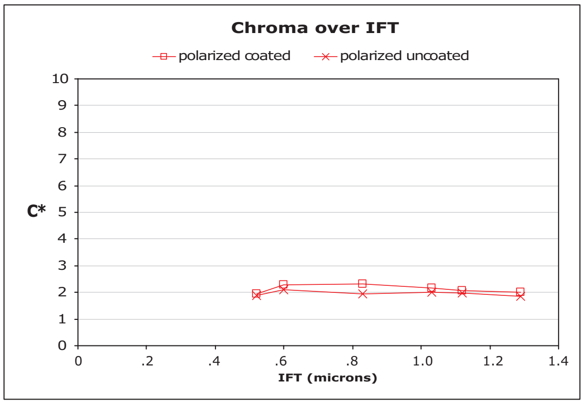


Figure 12: *The chroma (C*) response of polarized and unpolarized readings of silver metallic color samples of different IFTs.*

Conclusion

For process control of metallic color samples using 0/45 geometry, polarized readings have better sensitivity than unpolarized readings in monitoring changes in IFT. This holds true for both metallic color samples. Additionally, for bronze metallic color samples, Status I densities are more sensitive than Status T densities.

Likewise, polarized readings have a more sensitive lightness (L*) response than unpolarized readings for both bronze and silver metallic colors.

For the bronze metallic color samples, there was a difference between the Status T and Status I density readings, with Status I being more sensitive to IFT changes. For the silver metallic colors however, since the visual filter is being used there is no difference between the different status densities.

Analyzing the chromatic dimension for bronze metallic colors, which can be expressed either in chroma (C*) or a* and b*, it was concluded that an unpolarized filter provides higher sensitivity. For the silver metallic colors, there was no difference between the two filters, due to the strong achromatic component of the silver color.

Suggestions for further research

This analysis used only silver and bronze metallic colors. In order to be able to generalize the findings, it is suggested to conduct the same experiment with various metallic colors of different formulations.

It would be also important to extend the metrological specification by including the integrating sphere and goniospectrophotometry. Additionally, the extend to which these findings would be identical using a D50/2-degree observer would be interesting to determine.

A final suggestion for further research would be to correlate IFT changes to the perceived color change, involving an analysis mostly of the appearance attributes of metallic colors.

Acknowledgements

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