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Selecting Best Ink Color for Sparse Watermark

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Abstract

A method of watermarking print ready image data used in the commercial packaging industry is described. A significant proportion of packages are printed using spot colors, therefore various tools to support watermarking spot colors are required. Previously we have described a method which assumes that the package design contains process colors CMY as well as the spot colors to insert a chrominance watermark [1]. Some package designs do not include the process colors CMY or are being printed with a print process which allows limited overprinting, and require a different approach. For simplicity of press control, a binary watermarking system was developed. The binary watermark is inserted in a single ink color with values of 0 and 100%.

For the binary watermark to be used in a package design, a method is required which evaluates the ink colors used in a package design and ranks them for use with a modern barcode scanner at the Point of Sale (POS) station.

Introduction

Nearly three years ago, Digimarc announced Digimarc Barcode for the packaging industry. This introduction has many advantages to a traditional UPC code, perhaps most notably an improvement in the check-out efficiency and customer experience. The Digimarc Barcode can potentially cover the entire package with a minimal impact on the graphic design which eliminates the need to search for the barcode at checkout. Adding the Digimarc Barcode to the graphic design is the last step before the digital image is sent to press, and is called enhancement.

Two common ink systems are used to print commercial packages. The first ink system uses process colors, which includes Cyan, Magenta, Yellow and Black, referred to as CMYK. This technique is used to simulate a wide range of colors, by mixing the ink on a substrate and printing half tone dots. The second system is called spot colors, which are custom pre-mixed inks designed to achieve a certain color when printed on a specified substrate. In practice, most print jobs include a combination of both systems.

The motivation to enhance spot colors is that a significant portion of packages are printed using spot colors or contain some spot color regions. Spot colors are used in commercial packaging for a variety of reasons: to reduce cost, color accuracy, color consistency, to achieve colors outside of the traditional color gamut and to achieve special effects such as fluorescents, metallic or optically variable inks.

Modern barcode scanners are monochrome imaging devices typically with red LED illumination. The red LED is a narrowband light source with a wavelength of 660 nm, which implies that the scanner can only see image content on packages printed with inks that have low reflectivity at this wavelength, such as Cyan or Black.

Digimarc has developed a set of tools which give the designers different options on how to enhance a package. The tools were created to help designers mark a variety of different types of artwork, which will be printed with a variety of different technologies. To be more robust to press variation, a binary watermarking system was developed. The binary watermark is typically inserted in a single ink color with values of 0 and 100%.

The majority of process and spot colors will work in enhancing a piece of artwork using the binary technique. However, some colors will be more or less visible to either the human visual system or the POS scanner. The objective of this work is to give designers information on how to select the best ink color for the binary watermark when (re)designing commercial package artwork. This information is conveyed using a metric called Digimarc Barcode Score (DB Score) which is calculated for each ink color with a value from 0 to 100. A larger number means that the ink color has a higher robustness per unit visibility, resulting in a mark which can be read by a POS scanner, with low watermark visibility.

In this paper, we describe tools to help select the best binary watermark to use. This requires a method which evaluates the ink colors used in a package design and ranks them for use with POS scanners.

Background

Color Perception

The success of a binary watermark is dependent on the color of the ink. Due to the common use of red LED illumination, watermark signals are most recognizable in colors which absorb light in the red region of the spectrum, while colors with low absorption are not seen by a traditional POS scanner. The POS scanner used in this paper has its peak spectrum at 660 nm as shown in Figure 1. For reference, the figure also shows the spectral reflectances of a set of CMYK process inks.

A comparison between a full color digital original and a POS scanner's view of the same label can be found in Figures 2 and 3. Since essentially no light is absorbed by the red ink in the 660 nm part of the spectrum, the red regions of the artwork appear as white the POS scanner. Conversely, the cyan, green and black colors are seen as different shades of gray.

The objective of this work is to give designers information on how to select best ink color for the binary watermark when (re)designing commercial package artwork. This information is conveyed using the DB Score metric which is calculated for each ink color with a value from 0 to 100. A larger number means that the ink color has a higher robustness per unit visibility, resulting in

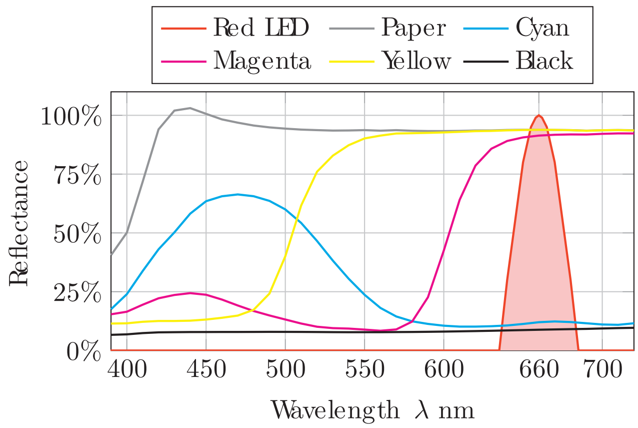

Figure 1. *Spectral reflectance of CMYK process inks as measured using X-Rite i1Pro spectrophotometer. Graph also shows spectrum emitted by red LED centered at 660 nm*

Figure 2. *Digital Source File, the red peppers have some black ink to create shadows.*

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Figure 3. *View of POS scanner (with narrow-band red LED), this model has two cameras, creating the two perspectives. The red ink appears white.*

Figure 4. *Peanut butter Jar Label - For illustration bottom left of the label is shown at 300% enlargement below*

a mark which can be read by a POS scanner, with low watermark visibility.

Enhancing White Regions

Many packages have large white regions (see Figure 4 for example).

With CMYK artwork, large white regions can be watermarked using a low CMY tint. However a significant percentage of food packaging is printed with flexography using several spot colors and process black, without process CMY. Dry offset is another printing process which is widely used in food packaging which typically uses several spot colors and black. In addition dry offset only allows limited overprinting of inks, and has very high dot gain. In these applications, where CMY ink is not available and/or the press has high dot gain, a binary watermark is a good solution. The example shown in Figure 4, was used by a customer to obtain robust watermark detection using a POS scanner with low visibility.

A binary watermark is a signaling scheme which is designed to work with the above types of printing technology. Details of the binary watermark technology are given by [2].

However a binary watermark requires an ink color which is seen by the traditional POS scanner, and is of low visibility to the human visual system. Figure 5 shows the 1931 CIE standard observer color matching functions, which highlight the visual system's lower sensitivity to the higher wavelengths, i.e. 660 nm. Low visibility for a white region of a package, means that the area would still appear close to white with little texture after the watermark is applied.

An ideal ink shown in Figure 6 would have a spectrum very close to the spectrum of the substrate in the visible region and would only absorb some percentage of light in the 660 nm wavelength region. In practice, different POS scanner models use red LED's which have peak wavelengths from about 630-690 nm. Therefore the ink needs to have a reflectance difference from the background color in this wavelength range for it to be seen by the various POS scanner models.

DIGIMARC BARCODE (DB) SCORE METRIC

In order to rank ink colors to carry a binary watermark, we need to estimate the robustness per unit visibility. The robustness

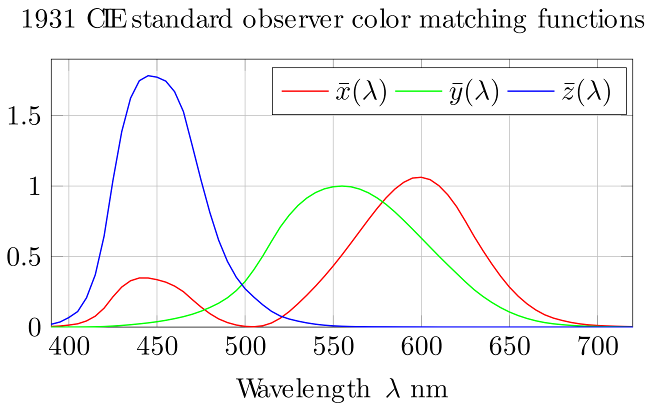

Figure 5. *1931 CIE 2° standard observer matching functions*

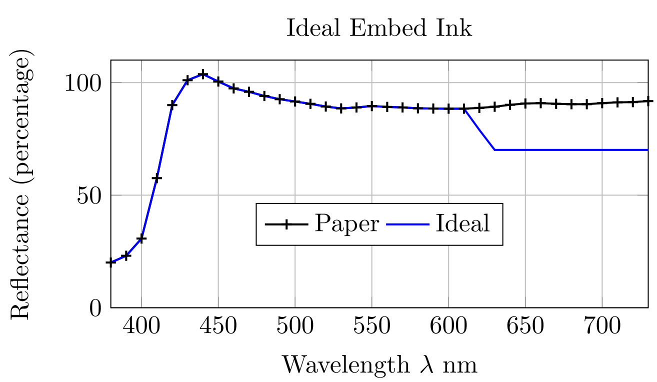

Figure 6. *Reflectivity curves for an Ideal embed color relative to white paper.*

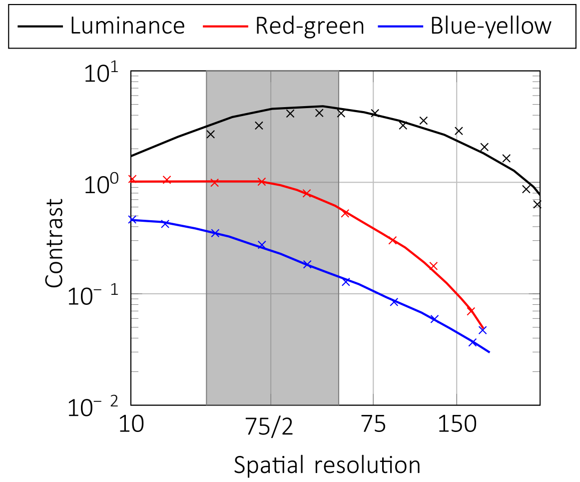

Figure 7. *Contrast Sensitivity Function of Human Eye*

of a binary watermark is proportional to:

$$\Delta 660 = R660_{substrate} - R660_{100\%Ink} \quad (1)$$

where, $R660_{substrate}$ is the reflectivity of the substrate at 660 nm and $R660_{100\%ink}$ is the reflectivity of 100% ink at 660 nm.

The visibility error introduced by a binary watermark can be split into 2 components.

1. Color shift, introduces a color match visibility error (Ecm).
2. Texture, introduces a watermark visibility error (Ewm).

The color match visibility error is proportional to the standard ΔE equation.

$$Ecm = ((\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2)^{1/2} \quad (2)$$

where, ΔL^* is the lightness difference between 100% of the ink and the substrate, Δa^* is the chrominance difference in a^* between 100% of the ink and the substrate and Δb^* is the chrominance difference in b^* between 100% of the ink and the substrate.

The watermark visibility error can be represented as:

$$Ewm = ((\Delta L^*)^2 + ((\Delta a^*)/8)^2 + ((\Delta b^*)/16)^2)^{1/2} \quad (3)$$

where, the weightings for the contributions due to ΔL^*, Δa^* and Δb^* are calculated from the human Contrast Sensitivity Function (CSF) measurements for luminance and chrominance shown in Figure 7.

Background on CSF measurements for luminance is provided in [3]. Background for measurements for chrominance is provided in [4].

A binary watermark signal contains most signal energy over the spatial resolutions shown by the gray box in Figure 7. If the luminance and chrominance CSFs are integrated over this gray box region, the resultant energy ratios approximate the relative weights that should be applied to CIE L*, a* and b* to estimate *Ewm*.

Robustness per unit Color match Visibility (Ewm) is:

$$RCV = \Delta 660/(((\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2)^{1/2}) \quad (4)$$

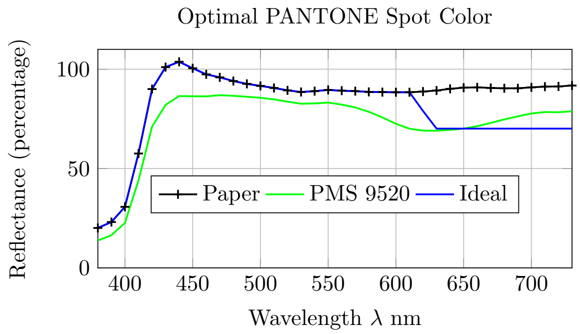

Figure 8. *PANTONE 9520 compared to ideal embed color*

And, Robustness per unit Watermark Visibility (RWV) is

$$RWV = \Delta 660/(((\Delta L^*)^2 + ((\Delta a^*/8))^2 + ((\Delta b^*/16))^2)^{1/2}) \quad (5)$$

If color match error and watermark error are assumed to have equal importance, then the DB Score is assumed to be a sum of RCV and RWV.

$$DBScore = RCV + RWV \quad (6)$$

DB score values were calculated for a spectral database of PANTONE colors which have been measured from the PANTONE Formula series and PANTONE Neons and Pastels on coated stock.

A range of DB Scores from this analysis are shown in Table 1 below.

	Color Name	Δ660	DB Score
	PANTONE 9520	20	100
	PANTONE 9524	40	96
	PANTONE Green 0921	50	92
	PANTONE 9540	19	91
	PANTONE 9500	34	88
	PANTONE 9541	21	88
	PANTONE 9521	26	87
	PANTONE 9502	28	84
	PANTONE 9522	26	84
	PANTONE 9523	24	83
	PANTONE 206 C	5	2
	PANTONE 2024 C	3	2
	PANTONE 223 C	2	2
	PANTONE 185 C	4	2
	PANTONE 1585 C	3	2
	PANTONE 224 C	3	2
	PANTONE 2346 C	3	2
	PANTONE 2026 C	3	2
	PANTONE 1555 C	1	2
	PANTONE 2027 C	4	2

Table 1 DB Scores of Pantone Spot Colors on coated stock

The spectral reflectivity of the highest ranking color PANTONE 9520 is shown in Table 1. It can be seen that PANTONE 9520 is a good approximation to the 'Ideal Embed' color.

Two of the highest ranking colors, PANTONE 9520 and Green 0921 were used in an engineering test to print a binary watermark on an offset press with white coated stock (printed results are available for viewing). These inks have also been used on packages enhanced for use by customers. Part of a package using PANTONE 9520 is shown in Figure 4. The resultant watermark could be detected by a barcode scanner, and had very low visibility.

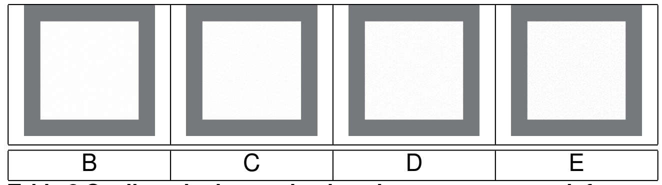

Table 2 Quality ruler increasing in enhancement strength from B (slight) to E (strong). The enhancement should be more visible if the artwork is enlarged.

In Table 1, the reflectivity difference at 660 nm between the solid ink and substrate is called Δ660. For robust detection of a binary watermark on 80 pound coated paper stock, a minimum Δ660 of about 20% is required. Commercial packages are often printed on a poly substrate with opacity significantly less than 1. Low opacity results in a reduction of Δ660 by about 50% compared to a good quality coated paper stock. In this case an ink with a larger Δ660, such as Green 0921, should be used so that a minimum reflectivity difference of 20% is maintained.

METRIC TESTING AND VALIDATING RESULTS

The metric described above consists of a robustness and a visibility component. The robustness component is obtained from the difference between the paper and ink spectral responses at 660 nm. The visibility component of the metric only depends on the ink CIELAB values and was tested using an Epson Stylus 4900 ink jet proofer. A psychophysical test was conducted on a range of ink colors to measure the subjective visibility. These subjective tests were conducted on a range of ink colors which were selected to cover a wide range of color match and watermark visibilities. The correlation between the subjective tests and the objective metric was measured.

To ensure accurate CIELAB values were being used in the objective metric, solid patches of all the test colors were printed and measured.

Psychophysical experiment

To test the visibility component of DB score a psychophysical experiment was conducted. As discussed in the Background section, the visibility degradation introduced by the watermark consists of two parts, a color shift and a texture error.

A set of 12 observers were asked to rate their perception of the image degradation of 12 color patch samples using a quality ruler. The quality ruler (illustrated in Table 2) was a binary mark that increased in enhancement strength from left (B) to right (E). The quality ruler was made with black ink and the percentages of black ink used in the binary mark were chosen to have equal Lightness increments, so that the watermark visibility increments between B, C, D and E are approximately equal.

All 12 participants passed the Ishihara color test. There were four female and 8 male participants. Their professions and experience varied, several are designers and others are engineers.

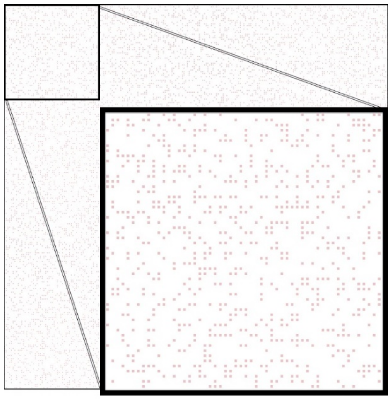

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Figure 9. For illustration only, a zoomed in version of the enhanced patch.

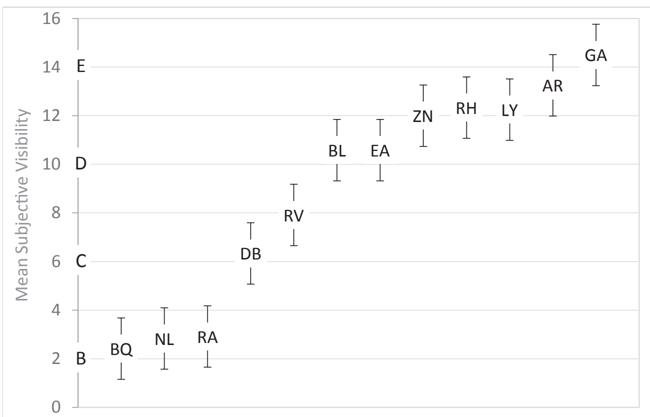

Figure 10. *The mean observer responses with standard error bars are plotted. The quality ruler locations are labeled on the left side of the plot, increasing in enhancement strength from B (slight) to E (strong)*

Several people had never participated in a visibility experiment.

Thumbnails of 10 of the samples are illustrated in Table 3 and an enlarged example is illustrated in Figure 9. In addition to showing the 10 samples, Table 3 also has a solid patch of each PANTONE color to more easily see the color. The third thing included in the table is the PANTONE number. The choice of PANTONE colors were chosen to be approximately equally spaced in visibility across the quality ruler samples.

The experiment and the quality ruler samples were all printed with an Epson Stylus 4900 on GMG semimatte 250 proof paper using the GMG ColorProof RIP.

The enhanced samples were viewed one at a time at a viewing distance of approximately 12". The observers were asked to judge the overall visibility of each patch compared to the visibility of the standard ruler patches. The mean observer scores for the 12 enhanced samples are plotted in Figure 10. In general the colors on the far right are lighter.

Two of the twelve PANTONE color samples in the subjective visibility testing were repeats. Sample BL was the same as EA, and sample ZN was the same as LY. It can be seen that the

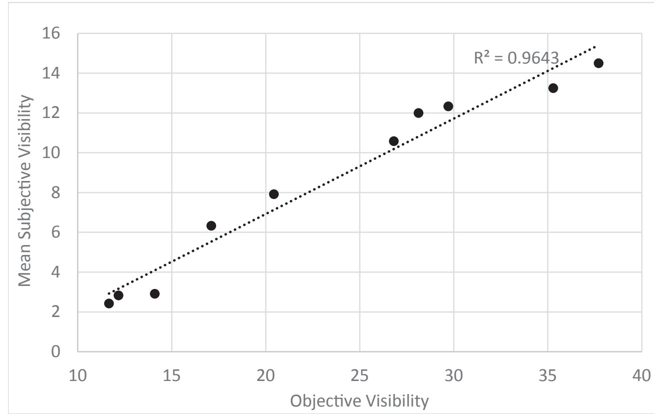

Figure 11. *Correlation between subjective mean and objective visibility metric*

subjective measurements of BL and EA, and of ZN and LY are very similar.

Comparison with Objective Model

The correlation of the remaining 10 subjective visibility results to the objective metric described in DB metric section are shown in Figure 2 below.

A high correlation can be seen between the subjective mean and the objective visibility metric.

METRIC USE IN DESIGN ANALYSIS TOOL

The DB Score metric can be used in a Design Analysis Tool as described below:

1. If the designer is working on a new design and the color palette has not yet been established, they could choose a color which still meets their needs and has a high DB Score.
2. If the designer is looking to pick a single color to use for a binary watermark, for the colors in their existing artwork they should choose the color with the highest DB Score.

It is planned to use the DB Score metric together with a physical book for a designer to visualize the effect of watermarking a spot color. This book would be similar to the Pantone Bridge Guide which compares a solid PANTONE spot color to the closest process color match. In this case, the solid PANTONE spot color is compared to a watermarked version of the spot color.

However since a physical book with a large range of spot colors would be expensive to produce, we decide to simulate the spot colors using PANTONE Extended Color Gamut (ECG) printing. PANTONE ECG has a large gamut which covers 90% of PANTONE spot colors while allowing a total maximum ink coverage of 257% for any given color if required. A PANTONE certified printer will be used since accurate CIELAB values are required for faithful representation of the visibility of the watermarked samples. Also conventional screening will be used for it to be representative of commercial printing.

CONCLUSIONS

DB Score accurately predicts the best color to use for a binary watermark in white areas of a design. The visibility component of the metric can be used to quantify binary watermark visi-

RA	BQ	DB	NL
PANTONE 9520 C	PANTONE 9541 C	PANTONE 9400 C	PANTONE 9043 C
RH	ZN	RV	BL
PANTONE 2707 C	PANTONE 9382 C	PANTONE 664 C	PANTONE 9263 C
	AR	GA	
	PANTONE 503 C	PANTONE 524 C	

Table 3 10 test samples, with a solid version of each color showing the PANTONE number.

bility for a designer. Initial testing shows that the visibility metric also works with a single channel continuous tone watermark.

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Author Biography

Alastair Reed received his B.Sc degree in Physics from Imperial College, London in 1975 and a Ph.D. in Physics from the University of North London in 1979. He went on to do color image processing for 5 years at Crosfield Electronics in Hemel Hempstead, England and 12 years at Cymbolic Science International in Richmond, Canada before coming to Digimarc in Portland, Oregon 16 years ago. His work at Digimarc has involved modeling the human visual system and the print process, to reduce watermark visibility.