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Using watermark visibility measurements to select an optimized pair of spot colors for use in a binary watermark

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Abstract

Spot colors are widely used in the food packaging industry. We wish to add a watermark signal within a spot color that is readable by a Point Of Sale (POS) barcode scanner which typically has red illumination.

Some spot colors such as blue, black and green reflect very little red light and are difficult to modulate with a watermark at low visibility to a human observer. The visibility measurements that have been made with the Digimarc watermark enables the selection of a complementary color to the base color which can be detected by a POS barcode scanner but is imperceptible at normal viewing distance.

Introduction

Spot colors are widely used in the food packaging industry. We wish to add a watermark signal within a spot color that is readable by a Point Of Sale (POS) barcode scanner which typically has red illumination at a wavelength of 670 nm.

Some spot colors such as blue, black and green reflect very little red light and are difficult to modulate with a watermark at low visibility to a human observer. The visibility measurements that have been made with the Digimarc watermark enables the selection of a complementary color to the base color which can be detected by a POS barcode scanner but is imperceptible at normal viewing distance

Digimarc is interested in models which predicts the visibility of its watermark signal, allowing the maximum signal to be added to an image within a visibility constraint. Developing these visibility models required accurate subjective measurements of the Chromatic Contrast Sensitivity of human observers to the watermark signal. These visibility models are used to minimize the visibility of a sparse watermark by selecting 2 spot color inks that change in a color direction which is of low visibility to the human visual system. Color direction is a change from the base color in some direction of the a*-b* plane. Ideally when the pair of inks are used in a binary watermark, the watermark would be detected by a barcode scanner but be almost imperceptible to a human observer.

Visibility Measurements

This section describes the setup for the psychophysical experiment for collecting thresholds of just noticeable chromatic Digimarc watermark. The thresholds measured correspond to 1 Just Noticeable Difference (1 JND).

The experiment was performed on a 10-bit EIZO ColorEdge CG248-4K 24" display at its native 4K resolution. The white point of the display was set to a D50 chromaticity at 160 cd/m2 luminance. The gamma of the display was set to 2.2. The display was calibrated, through the Psych toolbox (Brainard [1]), using a third-order polynomial transform between the device RGB values and the displayed XYZ tristimulus.

The chromatic stimuli were obtained by modulating the Digimarc watermark along six different directions in the a*-b* plane of the CIELAB color space - 0°, 30°, 60°, 90°, 120°, and 150° with respect to the right a*-axis. Prior to modulation, the watermark was multiplied by a circular 2D Tukey window, whose flat area (its diameter) corresponded to a visual angle of 2° subtended at the observer's retina. The windowed watermark was spatially added to one of the six directions in the a*-b* chromatic plane of the base color (color center). We used a total of 26 different CIELAB color centers. Along the six chromatic directions, the strength of the modulated watermark was varied in terms of Δa^*b^* - the Euclidean distance between the color center and the furthest watermark pixel in the a*-b* plane. Examples of the watermark stimuli, modulated at six different color centers and chromatic directions, are shown in Figure 1.

Ten observers, of which five males and five females, with normal or corrected-to-normal color vision, participated in the experiment. The stimuli were observed in a dark room at 60cm viewing distance. The whole experiment was split into six sessions. A maximum of five color centers were measured in a single session. The observers were adapted to each color center before the JND measurement. The JND itself was obtained after 30 trials of the QUEST adaptive staircase method using a four-alternative-forced-choice input: the observer was supposed to click on only one of the four areas that contained a watermark modulated in a randomly chosen chromatic direction. Each observer responded to a total of 4680 displayed stimuli (30 trials x 6 chromatic directions x 26 color centers). The average time for a single response was around 4 seconds; the total experiment time for all observers was around 53 hours. The QUEST method is described in the paper by Watson [2].

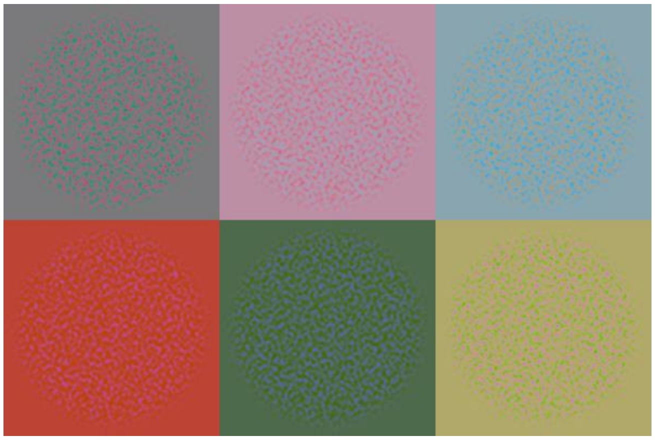

Figure 1. Digimarc watermark modulated on six color centers in different CIELAB chromatic directions: Top row: 0°, 30°, and 60°; Bottom row: 90°, 120°, and 150°

Color Description	Lab
Mid-gray	50,0,0
GRACoL Green	46,-32,2
LightGray-SpotGreen	56.5,-18.5,10
MidGray-Spot Green	44,-18.5,10
Black-Spot Green	29,-18.5,10
Spot Green	38,-37,20
GRACoL Blue	33,4,-23
LightGray-SpotBlue	52,4,-22.5
MidGray-Spot Blue	39.5,4,-22.5
Black-Spot Blue	24.5,4,-22.5
Spot Blue	29,8,-45
Light Gray	75,0,0
LightGray-Magenta	62,29,-1
Magenta	49,58,-2
LightGray-Cyan	61,-12.5,-9.5
Cyan	47,-25,-19
LightGray-Yellow	77.5,-1.5,30
MidGray-Yellow	65,-1.5,30
Black-Yellow	50,-1.5,30
Yellow	80,-3,60
LightGray-Red	63,30,19
Black-Red	35.5,30,19
Red	51,60,38
Black	20,0,0
Yellow (gray adapt 80,0,0)	80,-3,60
Yellow (gray adapt 50,0,0)	80,-3,60

Table 1. Color Centers Measured

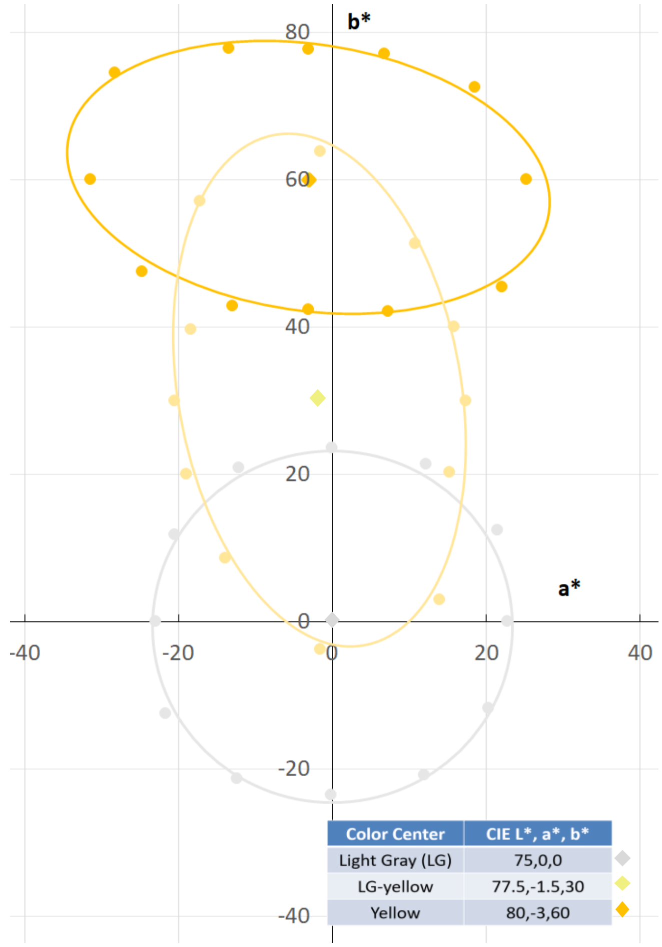

Figure 2. 1 JND visibility ellipses at high lightness

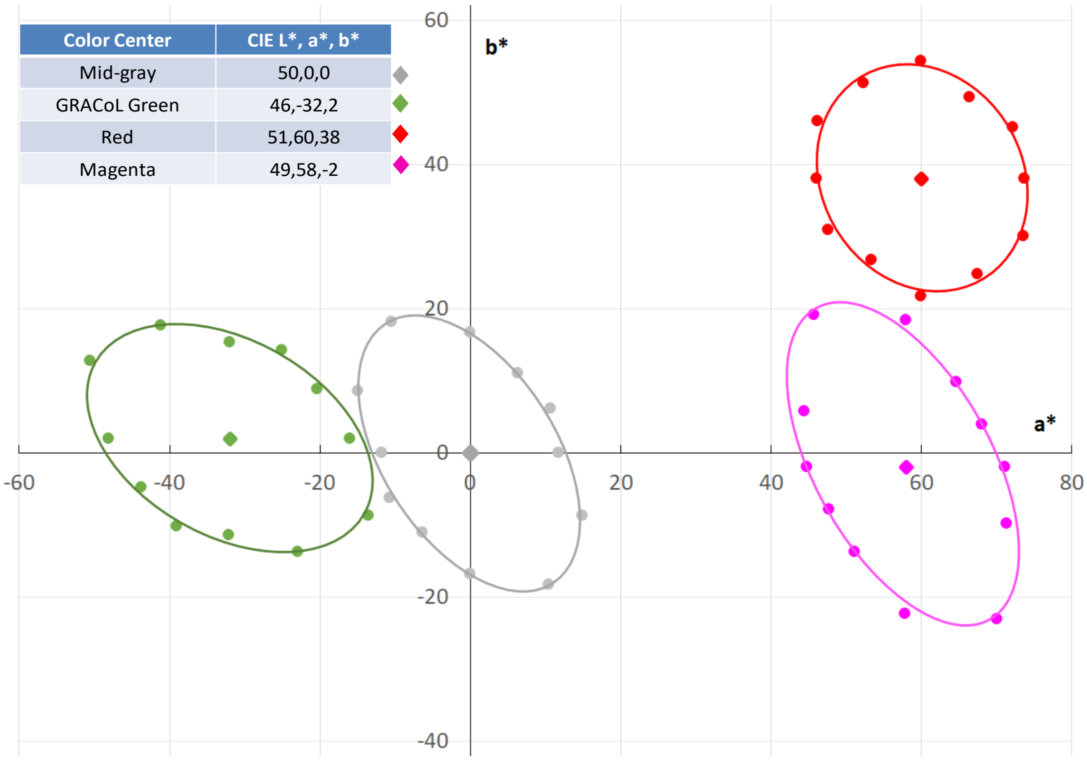

Figure 3. 1 JND visibility ellipses at medium lightness

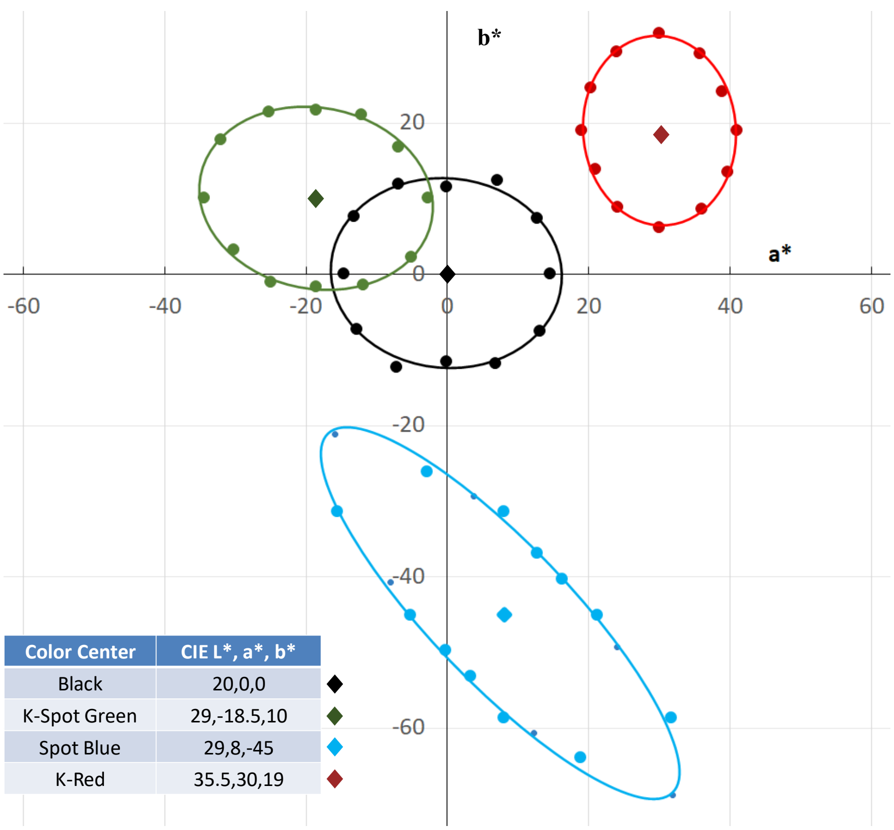

Figure 4. 1 JND visibility ellipses at low lightness

Optimum Colors for Binary Watermark

Earlier work by Kitanovski [3] measured the chromatic contrast sensitivity of a Gabor function. In this paper, we measure the 1 JND visibility for a Digimarc watermark that is used in print. Digimarc watermarks are used in the Packaging industry as a machine-readable signal which can be used over the complete product lifecycle for various applications such as quality control in manufacturing, consumer engagement/check-out and recycling.

The 1 JND visibility envelope was measured at 26 different color centers that spanned the gamut of commercial CMYK printing, and a range of spot colors that are important in Packaging (see Table 1). A selection of measurements at high, medium and low lightness levels are shown in Figures 2, 3 and 4 respectively. The 1 JND thresholds are well defined by an ellipse. Every point on the ellipse represents a color direction from the base color in the center of the ellipse and watermarks applied to the base color in each of these directions are equally visible at 1 JND. The ellipse varies significantly in magnitude and direction of the major axis. The major axis is the minimum visibility direction. These shapes are very different from those predicted by spatial CIE Lab (Johnson [4]).

In some cases, the watermark has CIE L* changes and we need to know how such changes will affect watermark visibility. The visibility of a lightness watermark was measured at a high, medium and low lightness. The results are reported in Table 2 as the ratio of delta_a* to delta_L* at 1 JND.

Color Center	CIE L*,a*,b*	Delta_a*/Delta_L*
Light gray	75,0,0	5.9
Mid gray	50,0,0	13.1
Black	20,0,0	8.8

Table 2. Watermark Lightness Sensitivity

Table 2 shows that a much smaller change is required in delta_L* than in delta_a* to obtain 1 JND. To minimize watermark visibility, delta_L* should be close to zero.

Previous work by Reed [5], described how to select the best ink to use for a binary watermark in white regions of a package. The new method, described in this paper, is used for watermarking spot colors that have low reflectivity at 670 nm. Holes corresponding to a binary watermark are inserted in such a base color, so that light at 670 nm is reflected to the scanner. An example for PANTONE 541 is shown in Figure 5.

When the holes go to white substrate the watermark is very visible. Thus, the holes are filled with a second ink to reduce the visibility of the binary watermark. To minimize visibility, only colors which have similar L* to PANTONE 541 C were considered. The color difference can then be plotted on the a^*b^* plane together with the 1 JND visibility ellipse (data taken from section on Visibility Measurements). All inks within 1 JND of PANTONE 541 C were evaluated (see Figure 6), and PANTONE 2371 C was selected since it had the largest difference in reflectivity at 670 nm. This fill ink will be called the complementary fill color. A similar method can be used for any spot color with low reflectivity at 670 nm.

The spectra of the 2 inks selected are shown in Figure 7. The difference in reflectivity of the 2 inks at 670 nm allows the watermark to be detected by a barcode scanner. The watermark is almost imperceptible because the 2 inks are within 1 JND.

The non-uniformity of the space is illustrated by selecting a color with a similar Euclidean distance in the a^*b^* plane but in the maximum visibility direction (see Figure 8). In this case, the color is outside the 1 JND ellipse and the watermark is clearly visible.

Conclusions and Future Work

Visibility measurements have been made of a Digimarc watermark across a wide gamut of base printing colors. These measurements have been used to select a complementary fill color for a binary watermark of a base color with low reflectivity at 670 nm. The watermark has low visibility and reads robustly. The same method can be applied to any spot color which has low reflectivity at 670 nm.

The visibility measurements could also be used to create an accurate visibility model for watermarked flat patches of color.

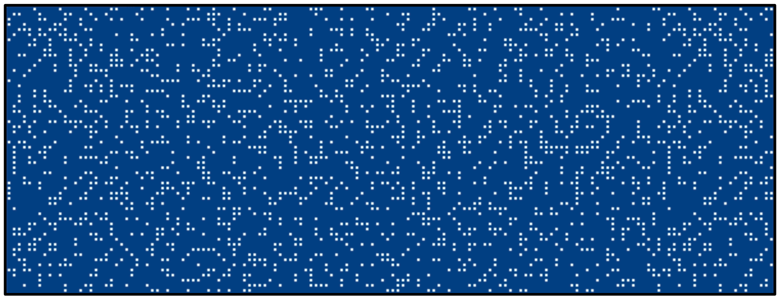

Figure 5. Binary watermark in single ink color (PMS 541)

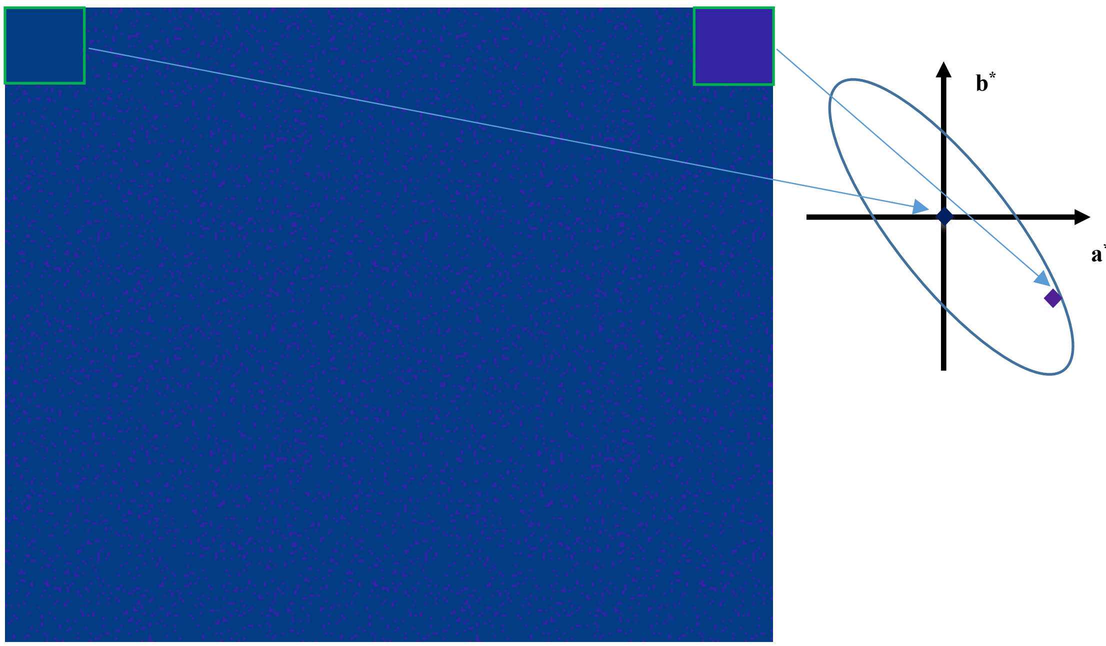

Figure 6. Binary watermark with holes filled using second ink color in minimum visibility direction

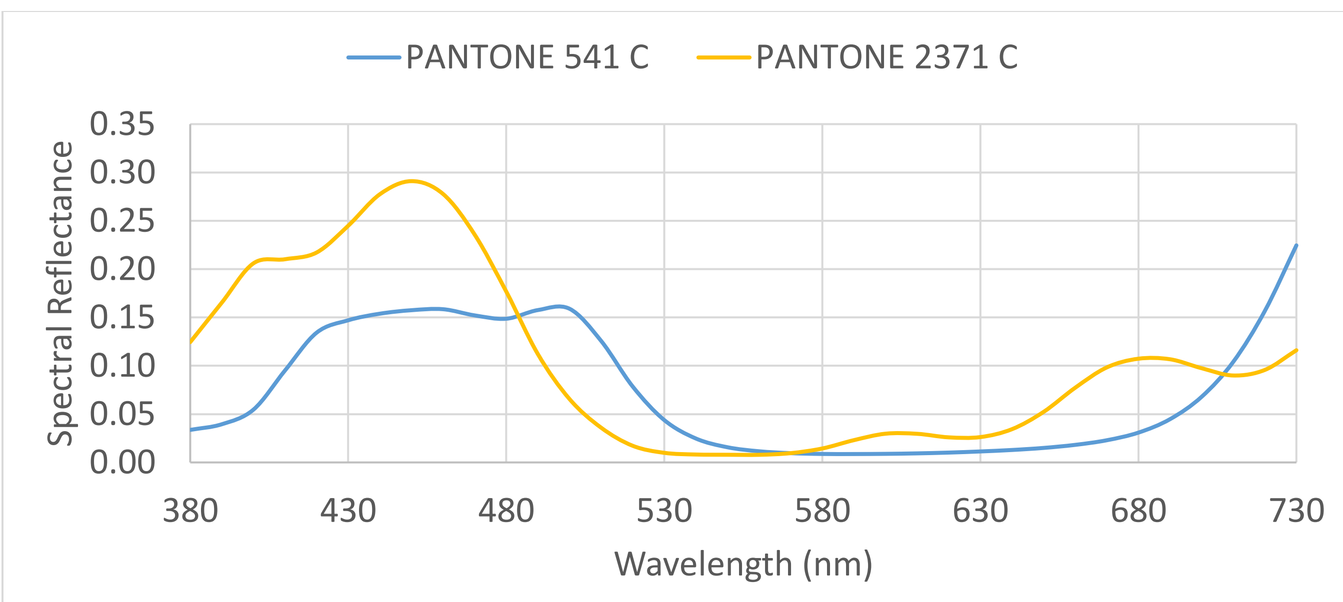

Figure 7. Spectral response of base and complementary fill colors

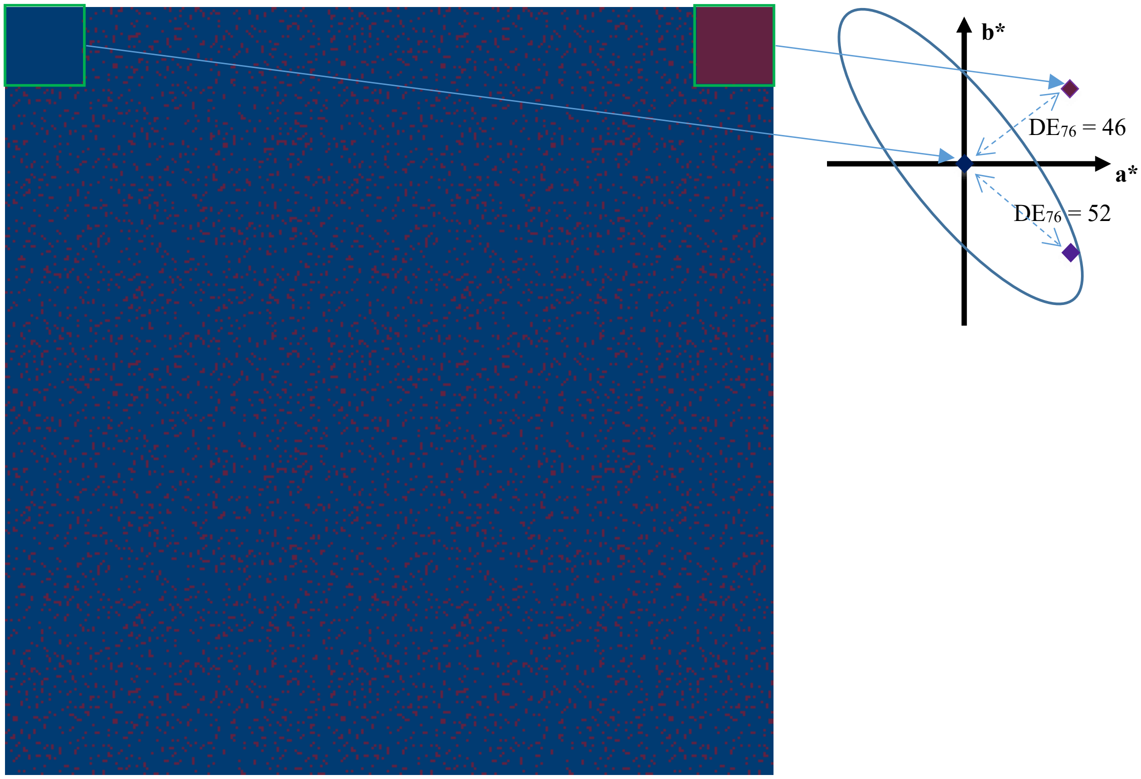

Figure 8. Binary watermark with holes filled using ink color in maximum visibility direction

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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 20 years ago. His work at Digimarc has involved modeling the human visual system and the print process, to reduce watermark visibility.

Vlado Kitanovski received his B.Sc. and M.Sc. degree in Electronics from the Ss. Cyril and Methodius University in Macedonia in 2005 and 2009, and a PhD in Computer Science from the Norwegian University of Science and Technology in 2019. Currently, he is a postdoctoral researcher at the Norwegian Colour and Visual Computing Laboratory at NTNU.

Kristyn Falkenstern has been working with the R&D team at Digimarc since 2013. Her work has largely focused on minimizing the watermark visibility while maintaining robustness with consideration to press variability. Prior to this she received her PhD in Signal and Image Processing from Télécom ParisTech. In 2009, she received her MSc at the London College of Communication, where she studied various methods of finding spectral reflectance estimates. Before starting her graduate work, she worked for 5 years on an image science team at Hewlett-Packard. She also holds a BS in Imaging and Photographic Technology from the Rochester Institute of Technology.

Marius Pedersen is professor at the Norwegian University of Science and Technology. His work is centered on image quality assessment; he has more than 60 publications in this field. He received his PhD in color imaging (2011) from the University of Oslo. He is currently the head of the computer science group in Gjøvik in the department of computer science, and the head of the Norwegian Colour and Visual Computing Laboratory, both at NTNU.