Watermarking Spot Colors

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ABSTRACT

Watermarking of printed materials has usually focused on process inks of cyan, magenta, yellow and black (CMYK). In packaging, almost three out of four printed materials include spot colors. Spot colors are special premixed inks, which can be produced in a vibrant range of colors, often outside the CMYK color gamut. In embedding a watermark into printed material, a common approach is to modify the luminance value of each pixel in the image. In the case of process color work pieces, the luminance change can be scaled to the C, M, Y and K channels using a weighting function, to produce the desired change in luminance. In the case of spot color art designs, there is only one channel available and the luminance change is applied to this channel. In this paper we develop a weighting function to embed the watermark signal across the range of different spot colors. This weighting function normalizes visibility effect and signal robustness across a wide range of different spot colors. It normalizes the signal robustness level over the range of an individual spot color's intensity levels. Further, it takes into account the sensitivity of the capturing device to the different spot colors.

Keywords: Watermarking, printed material, spot color, yellow saturation

1. INTRODUCTION

Digital watermarking techniques for various applications have been proposed in the past. Digital watermarks have been embedded in audio, video, digital still images and printed material. Digital watermarks embedded in printed material can be used for authentication, copy detection as well as for linking printed material with digital content. Alattar [1] shows examples of how a digital watermark bridges printed material with the Internet.

In digital watermark embedding, a common approach is to apply a tweak to the luminance values of the host image. Each luminance tweak can be additive or subtractive based on the value of the watermark signal at each pixel location. In the case of colored images, the watermark luminance tweaks are divided between the color channels based on a weighting function. Researchers have studied ways to make the watermark less perceptible to the human eye. Kutter, Jordan, and Bossen [2] suggested embedding the watermark strictly in the Blue channel for digital images displayed in the RGB color space. Reed and Hannigan [3] offered an adaptive method for the weighting function for printed color images in the CMYK color space. Their method takes advantage of the human eye's insensitivity to high frequency changes along the yellow-blue axis, and adaptively places most of the watermark signal in the yellow channel.

In the case of package printing, artwork designers often add spot colors to the basic four process colors: cyan, magenta, yellow and black (C, M, Y and K), especially when printing logos or other graphic elements that require precise color matching. When they are working with limited budgets, the artwork designers tend to limit the artwork to two- or three-spot colors. Spot colors can be viewed as color channels similar to the C, M, Y, and K channels. Each spot color channel has its own special characteristics and each has different capacity for hiding the watermark signal. A weighting function is needed to distribute the watermark signal across different spot color channels while maintaining equal robustness and equal imperceptibility through-out the printed art design.

Our method for deriving the weighting function is based on the luminance ranges of the different spot colors, the intensity level of the spot color at a given pixel location as well as the yellow-saturation level of each spot color. In Section 2, we derive the weighting function. In Section 3, we show results based on printed material using an offset press. Then, we conclude the paper with discussion in Section 4 and conclusions in Section 5.

2. WEIGHTING FUNCTION

In the printing environment, artwork is divided into separate channels. Each channel represents a specific color ink and is, generally, represented as a gray scale channel. For four color process printing, the cyan, magenta, yellow and black (C, M, Y, and K) channels are each transferred onto a plate and labeled for the pressman to apply the correct ink to the plates at the press. Similarly, spot colors are represented as channels of intensity values and the print plates are made based on these intensity files and labeled with the correspondent spot color. In a spot color's digital file the intensity value of a pixel corresponds to the amount of ink coverage on the paper at the specified pixel location. Intensity values are typically referred to as percent coverage (example 100% Yellow) and can be represented in the digital form by 8bits giving them a range from 0-255 intensity-level, where 100% intensity corresponds to 255 intensity-level and 0% intensity (no ink) correspond to 0 intensity-level. In the digital form, the same digital file that corresponds to 100% intensity Yellow can also represent a 100% intensity Black. When a digital file of a spot color (8-bit intensity levels) is embedded with a watermark, the modified image is used to create a single plate for print. If the pressman applies two different spot color inks (Black and Yellow) to this plate, at press time, the two prints will conceal the watermark to different degrees. If a capturing device (camera or scanner) is used to capture each of the printed files into a digital file, then, when we use a detector to detect the watermark, the watermark signal in each of the two digital files will have a different level of robustness. In a given watermark system, robustness is a measure of the strength of the watermark after printing and measurement with a capture device. The variation in robustness is due to the difference between the reflectance values of the two spot colors as well as the difference in the way the capturing devices respond to the different spot colors.

The range of luminance values, which a spot color can cover, varies based on the nature of the spot color ink. Also, the sensitivity of the capturing devices varies between different spot colors as does the level of noise in the captured data.

2.1 Luminance Mapping

In the above example, the digital file was embedded without the knowledge of the spot color ink that will be used for printing the image. This blind embedding in the case of spot colors will produce prints with wide variations in signal imperceptibility as well as in signal robustness. The variation in the signal imperceptibility and robustness can be easily demonstrated in an artwork that includes colors like Black, Yellow and mid-tone Green. Out of the three colors, Black will have the least capacity for hiding the watermark signal and will be the most robust at the detector. While Yellow will have the most capacity of the three for hiding the watermark signal and it will be the least robust at the detector. The mid-tone Green will have a mid-level hiding capacity as well as a mid-level robustness. Figure 1 illustrates the variations between the watermark robustness levels for 18 different colors from the Pantone Matching System PMS. In this case, we embedded 7 intensity gray scale files with Digimarc's watermark each at different watermark strength, where file 1 had the lowest strength and file 7 had the highest watermark strength. We created a plate for each file and used an offset press to print each of the strengths with 18 separate colors. We used a PC camera to capture frames of each printed image for all 18 colors. We ran the captured frames into a Digimarc detector and recorded the detection rates for each color at each of the 7 watermark strengths. The figure shows how the watermark robustness level varied with the different colors.

In watermarking still images, a common approach is to apply *a luminance tweak* to the luminance value of each pixel in the image. In the case of spot color still images, the only available data in the digital file is the *intensity values* of the pixels with no reference to their luminance values. To be able to apply a specific *luminance change* to a pixel in the spot color digital file, it is essential to know the spot color ink, which will be applied to the plate created from this digital file, at press time. The knowledge of the spot color ink will provide additional information, which will help in converting the image intensity data into luminance values.

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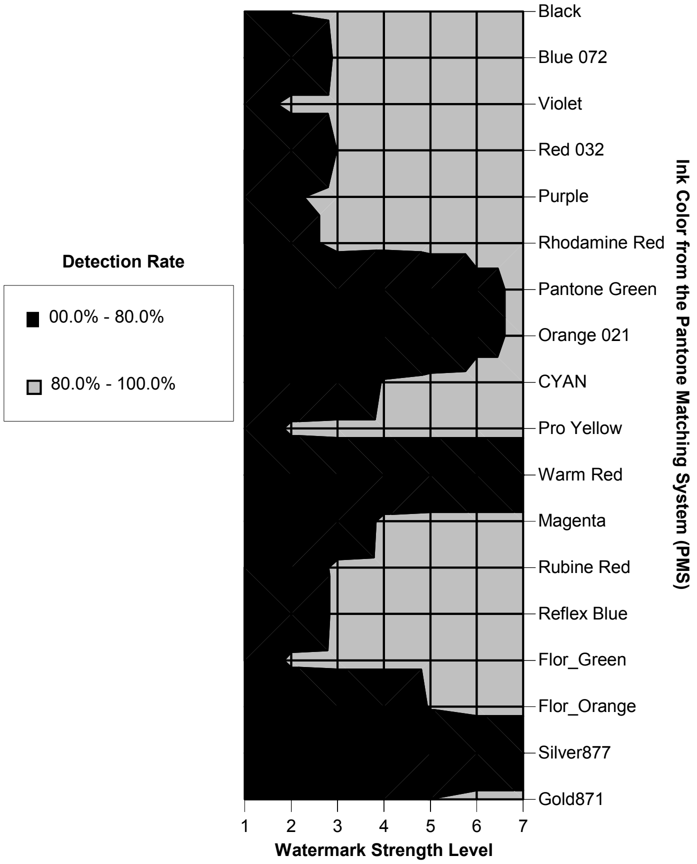

Figure 1. Detection rate for 18 PMS spot colors at varying watermark strength and color intensities

To watermark a gray scale digital file of a specific spot color, one needs to modify each pixel's *intensity value* in the digital file to produce specific *luminance changes* in the luminance values of the pixels, when printed using the specified spot color. As stated earlier, the watermark signal is commonly calculated in term of variations to the luminance values of the pixels not to their intensity values. One needs to convert the watermark values from luminance variations into intensity variations to be able to modify the digital file of a specific spot color.

Ink can be applied to the paper at different intensity levels to create a gradient of the color. For a given spot color ink, each intensity level produces a specific luminance value. A given color will produce the maximum luminance change when it is printed at 100% intensity (fully cover the paper). Since the maximum luminance value in an 8-bit digital file (255 luminance-level) corresponds to the absence of color, a spot color with high luminance value when printed at 100% intensity will cover a small range of luminance values over its full intensity range of 0 to 100%, while a spot color with low luminance value when printed at 100% intensity will cover a larger range of luminance values over its full intensity range. For example, the luminosity range between White (no ink), which has the highest luminance value

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(255 luminance-level) and Black at 100% intensity, which has the lowest luminance value (0 luminance-level), is 0-255 luminance-levels. This implies that, a change in the pixel's intensity value by 1 intensity-level in an 8-bit digital file, which corresponds to Black spot ink, will yield to a 1 level change in the luminance value of the pixel. On the other hand Yellow at 100% intensity has a luminance value of about 200 luminance-levels. This implies that Yellow spot ink has a luminance range of 200-255 luminance-level and in an 8-bit digital file, which corresponds to Yellow spot ink, a change in the pixel's intensity value by 5 intensity-levels will yield to about 1 level change in the luminance value of the pixel.

Since we assume, here, that embedding a digital watermark is a form of applying *luminance change* to the digital files. In the case of spot color embedding to introduce a specific change in the *luminance value* of a pixel, one has to map the level of the desired *luminance change* into a level of *intensity change* for the specific spot color. A simple way of mapping the luminance change into an intensity change is to calculate the luminance range of the specific spot color then to scale it to 255 levels.

$$\alpha_i = \frac{255}{(255 - L_i)} \qquad 254 \geq L_i \geq 0$$

Where,

α_i is the Luminance Mapping factor for spot color i

L_i is the luminance value of the spot color i when it is printed at 100% intensity.

The Luminance Mapping factor is used to convert the luminance changes to intensity changes. The intensity changes can then be applied to the pixels' intensity values.

For example, to apply a luminance change of 3 gray-level to a pixel's intensity value in a digital file, intended for Yellow Spot color ink. First calculate the Luminance Mapping factor for spot color yellow

$$\alpha_y = \frac{255}{(255 - L_y)}$$

And since $L_y = 200$ for spot yellow

$$\alpha_y = \frac{255}{(255 - 200)}$$

$$\alpha_y = 4.64$$

Thus one uses a Luminance Mapping factor of 4.64 to scale the Yellow ink's luminance range (55 levels) to the full luminance range (255 levels). Then, the same Luminance Mapping factor is used to map the luminance change (3 luminance-levels) into 14 intensity-levels, which is applied to the pixel's intensity value.

Companies that make spot color inks provide guides for the closest CMYK equivalent to a spot color. Although, CMYK representation of a spot color might give a poor representation of the spot color when the spot color lies outside the CMYK gamut, CMYK representation of a spot color is very accessible to artwork designers and can be used to

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calculate an approximate luminance value. Formulas for converting the CMYK representation of a color to its luminance value are widely available in the literature. One commonly used approximation can be found in [3].

$$C_0 = C + K - 0.01 \cdot C \cdot K$$

$$M_0 = M + K - 0.01 \cdot M \cdot K$$

$$Y_0 = Y + K - 0.01 \cdot Y \cdot K$$

Where,

C M Y and K are the cyan, magenta, yellow and black process color ink values

C_0 M_0 Y_0 are the cyan, magenta and yellow ink equivalent values after black has been recombined

All ink values cover the range of 0 – 100%

Then approximating

$$R_0 = 100 - C_0$$

$$G_0 = 100 - M_0$$

$$B_0 = 100 - Y_0$$

and from [4]

$$L = 0.299 \cdot R_0 + 0.587 \cdot G_0 + 0.114 \cdot B_0$$

Where,

R_0 G_0 B_0 are approximations to the NTSC red, green and blue primaries

L is the luminance value from 0 – 100%

A better way to obtain the luminance value of a spot color is to use a spectrophotometer, when available, to measure the luminance value of the color from the color swatches, which the spot color manufacturers supply as samples of their spot colors. The color swatches are always printed at 100% intensity level.

2.2 Yellow Saturation

Image Capturing Devices (cameras, scanners, etc) have different levels of sensitivity to different spot color inks. Capturing devices are designed to capture data in RGB color format, they use light sensitive elements, like CCDs,

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which record the amount of Red, Green and Blue components in the light reflected from the image or object. Due to the limited space on the sensing surface the number of the sensing elements corresponding to each of the three colors is optimized for the sensitivity of the human visual system. There are different distribution patterns for the sensing elements; the Bayer pattern is an example of the patterns that are used in capturing devices. In the Bayer pattern, the number of the Green sensing elements is double the number of each of the Blue and Red sensing elements. In Addition to the limited number of Blue sensing elements, it is common for the capturing device to coarsely compress the Blue channel's data; this will cause the Blue channel to be very noisy. Since 100% intensity Yellow is the absence of Blue in the RGB color format, the noise in the Blue channel corresponds to variations in the measured intensity of Yellow, which directly degrades the watermark signal.

In embedding a process color image with C, M, Y and K channels, the luminance tweaks are applied to each of the four channels using different weighting functions. The weighting functions modulate the tweak values for each of the four channels based on the channel's ability to hide the watermark as well as the sensitivity of the capturing devices to each of the channels. In the case of spot colors, the digital file has only one channel, which contains the intensity values of the pixels. One would need to modulate the earlier calculated intensity tweaks to offset the noise introduced by the capturing device.

Since the image capturing devices' noise level is higher when the spot colors has a high level of Yellow component (Yellow Saturation), one would need to modulate the intensity tweak levels based on the level of spot color's Yellow Saturation. Here, we use a formula similar to the one used in [5] to calculate the spot color's Yellow Saturation from its CMYK representation. After converting the CMYK equivalents of a spot color into its $C_0M_0Y_0$ equivalent (similar to Section 2.1), the following formula can be used to calculate the Yellow Saturation of the color:

$$\lambda = \frac{3Y_0 - 2C_0 - M_0}{600} + 1$$

Where,

λ is the spot color Yellow saturation factor

Y_0 C_0 M_0 are the cyan, magenta and yellow ink equivalent values after black has been recombined

The above formula produces a Yellow Saturation factor between 0.5 and 1.5. For Black, the Yellow Saturation factor is 1.0. For colors with high Yellow components, the Yellow Saturation factor is between 1.0 and 1.5. For colors with low Yellow components the Yellow Saturation factor is between 0.5 and 1.0. The Yellow Saturation factor is then used as a multiplying factor to modulate the intensity changes calculated in Section 2.1 before they are applied to the image intensity values. The implementation of the Yellow Saturation factor helps in adjusting the signal level to offset the noise level introduced by the capturing devices, due to optimal number of sensing devices and compression levels. The Yellow Saturation factor helps exploiting the colors with high capacity for hiding the watermark.

2.3 Intensity Compensation

Spot color artwork often include regions of flat areas as well as areas of gradually changing ink intensity. Areas with 100% ink coverage are referred to as "solid spot". In the case of solid spot, the digital intensity value of each pixel is at its maximum value (255) and the ink fully covers the printed media. Since the watermark changes are either positive or negative, it is not possible to apply a positive intensity change to a solid spot area since ink coverage cannot exceed 100%. Assuming that the watermark signal is symmetric around zero, this will mean that in the case of solid spot, the positive portion of the watermark signal will be lost. Similarly, when the pixel intensity value is close to zero, we lose the negative portion of the watermark signal.

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Portions of the watermark signal are lost whenever the applied watermark signal changes the pixel value to a value more than the maximum allowed value (255) or less than the minimum allowed value (0). The loss of portions of the watermark signal at the very high and very low intensity areas of the artwork, during the embedding process, causes the watermark to be less robust in these areas. In the case of areas with gradual change of the ink intensity, we find that the watermark robustness varies across the printed artwork. The watermark robustness decreases as the intensity levels move closer to the maximum and the minimum intensity values.

The watermark signal, generally, can be viewed as floating values normally distributed with mean zero and standard deviation of one. To obtain a desired signal strength, the watermark signal is uniformly modulated by a gain factor. Then the floating values of the watermark signal are uniformly quantized with a step size of one before they are applied as changes to the host image. Higher gain factor produce more quantization levels, hence, more robust watermark signals.

To normalize the watermark robustness across an artwork that has different intensity levels in the same spot color channel, we modulate the gain factor of the watermark signal at the high and low ends of the intensity spectrum to compensate for the lost portions of the watermark signal.

To illustrate this idea we use the following example: In the case of embedding a digital file for Yellow ink with gain factor G = 4.2, Yellow Saturation factor λ =1.4, and Luminance Mapping factor α = 4.64, the watermark intensity tweaks (before quantization) will have a standard deviation of 19.5. If the original file is flat with intensity values of 250, then any additive watermark tweak more than 5 will be clipped to 5, which will cause a loss of signal. To compensate for the signal loss in the additive side of the watermark signal we increase the strength of the subtractive portion of the watermark signal. The level of the compensation is calculated based on the level of signal loss. We calculate the Intensity Compensation factor β based on the standard deviation of the watermark signal and the pixel's intensity value.

$$\beta_i = 2 - \frac{255 - I_{xy}}{2\alpha_i \lambda_i G} \qquad \left(I_{xy} + 2\alpha_i \lambda_i G\right) \succ 255$$

$$\beta_i = 2 - \frac{I_{xy}}{2\alpha_i \lambda_i G} \qquad I_{xy} \prec 2\alpha_i \lambda_i G$$

$$\beta_i = 1 \qquad otherwise$$

Where,

β_i is the Intensity Compensation factor spot color i

I_{xy} is the intensity value of the x,y pixel

G is the gain factor

α_i is the Luminance Mapping factor for spot color i

λ_i is the spot color Yellow Saturation factor for spot color i

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3. EXPERIMENTAL RESULTS

In order to demonstrate the proposed algorithm, we conducted two experiments: the first experiment is a blind embedding experiment. We started with 5 different gray scale intensity files (92, 94, 96, 98, and 100% intensity). We embedded each file with a watermark at 7 different gain factors, independent of the spot colors. We created plates for the 35 files. We selected 18 different PMS spot colors with varying luminance ranges and printed the same plates with each of the 18 spot colors. The second experiment uses the proposed spot color embedding algorithm. We calculated the Luminance Mapping factor and the Yellow Saturation for each of the 18 spot colors and used these factors to modulate the watermark signal for each of the 18 colors. We embedded a different watermark for each of the 18 colors while calculating the Intensity Compensation factor dynamically at the pixel level. The second experiment produced 35 different files for each of the 18 colors. The files were labeled based on their corresponding colors and converted into plates. Each set of plates was printed with its corresponding color using the same offset press.

We used a good quality PC camera to capture digital images of each of the printed files. We set the camera to capture 22 images for each file at specific scale and rotation settings. The lighting conditions were held constant during the capturing process. The captured digital files were run through a watermark detector and we calculated the percentage of detected image for each of the spot colors at each of the 5 intensity levels.

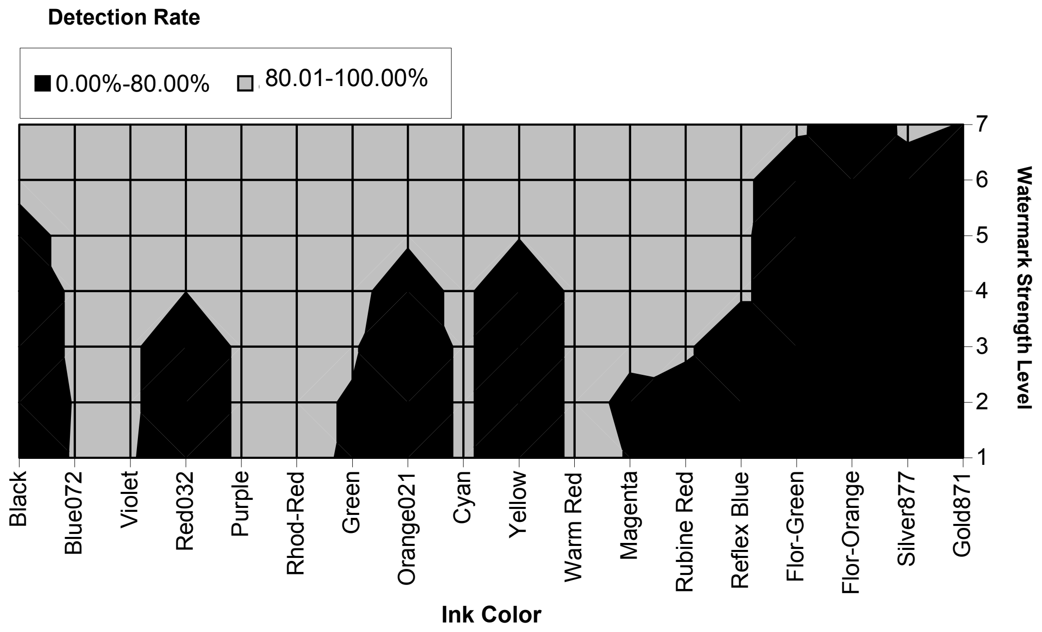

Figure 2. Results of blind embedding for 18 different PMS spot colors at 92% intensity

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Figure 2. illustrates the results of the blind embedding experiment at 92% intensity. The figure shows that the watermark robustness levels vary widely for different spot colors. On the other hand Figure 3. illustrates the results of the experiment with the proposed spot color embedding. The figure shows that the majority of the colors exhibit similar robustness levels.

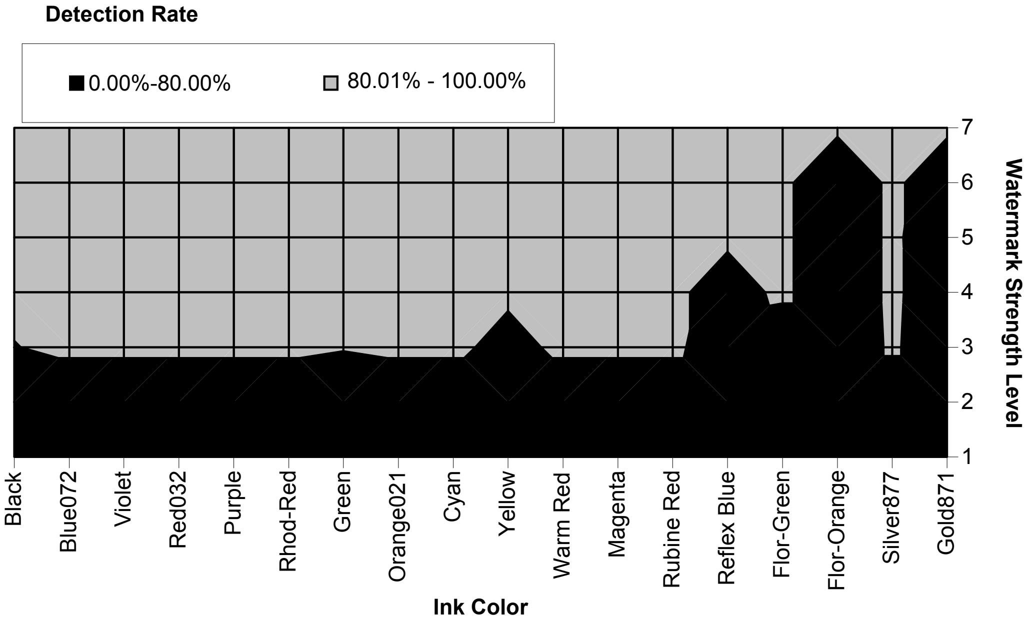

Figure 3. Results of proposed spot color embedding for 18 different PMS spot colors at 92% intensity

Figure 4. Illustrates the watermark robustness levels for the PMS Rhodamine-Red spot color at varying intensity values without correcting for the lost signal due to maximum boundary. Figure 5 illustrates the watermark robustness levels for the PMS Rhodamine-Red after using the Intensity Compensation factor to compensate for the lost signal. The robustness level reaches a detection rate of 75 – 100% consistently at a watermark strength level of about 3, after correction.

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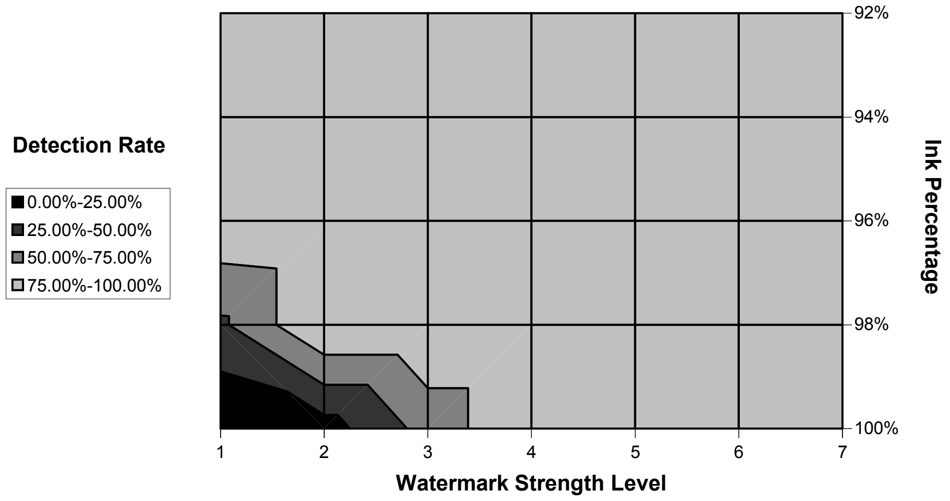

Figure 4. PMS Rhodamine Red Uncorrected

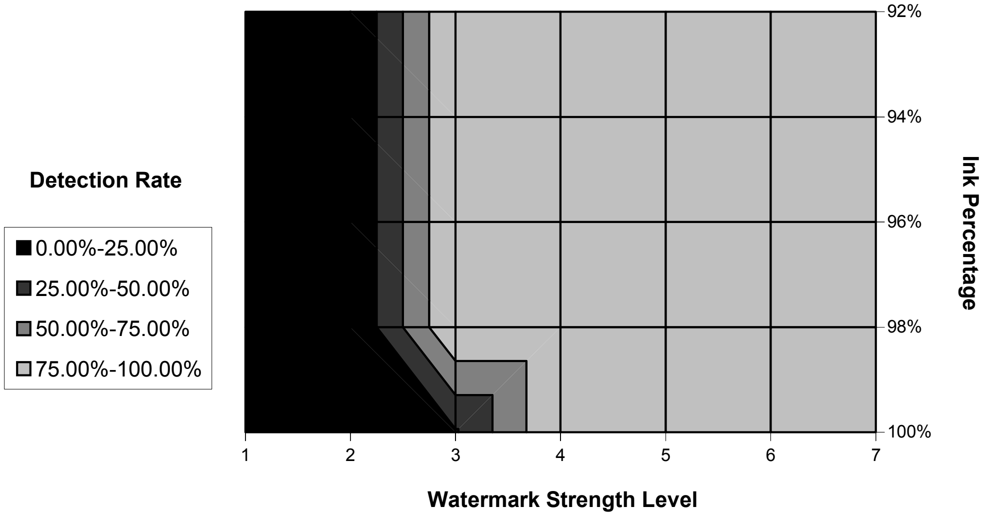

Figure 5. PMS Rhodamine-Red Corrected

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4. DISCUSSION

The test results from the two experiments in Section 3. illustrate the effectiveness of the proposed spot color embedding algorithms in normalizing the watermark robustness levels for different spot colors as well as for different intensity levels within the same spot color.

The proposed algorithm was not as effective in normalizing fluorescent colors (fluorescent Yellow, fluorescent Orange..) nor it was able to effectively normalize metallic colors (Silver and Gold). The fluorescent colors and the metallic colors are hard to represent in the CMYK domain as they are far outside the process color gamut. Thus, it is hard to calculate a meaningful luminance value for these colors as they are more sensitive to ambient light conditions than other colors.

The Intensity Compensation factor in the maximum and minimum intensity ranges was effective in normalizing the watermark's robustness levels but it does introduce an increase in the visibility of the watermark signal. Since the Intensity Compensation factor increases the signal in the opposite direction from the maximum or the minimum range to offset the loss of the signal, it introduces very small holes in the flat images, which can be noticed by the viewer.

5. CONCLUSION

In this paper, we develop an algorithm to normalize the watermark signal across the range of different spot colors. The algorithm requires the knowledge of some characteristics of the spot color to be printed. The algorithm is based on calculating the Luminance Mapping factor of the spot color, its Yellow Saturation value and its Intensity Compensation factor at each pixel location. Our experimental results have shown that the proposed algorithm is effective in normalizing the watermark robustness across a set of a wide range of colors.

Further work is needed to study the characteristics of some special colors like the metallic and fluorescent colors.

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REFRENCES

1. A. Alattar, "Bridging printed media and the Internet via Digimarc's watermarking technology"
2. M. Kutter, F. Jordan, F. Bossen, "Digital Signature of Color Images using Amplitude Modulation", SPIE 1997: 518-526
3. A. Reed, B. Hannigan, "Adaptive Color Watermarking", SPIE 2002: 222-229
4. R.W.G. Hunt, "The Reproduction of Colour in Photography, Printing and Television", 442 (Fountain Press, 1987)
5. S. Battiato, D Catalano, G. Gallo, R. Gennaro, "Robust Watermarking for Images based on color manipulation", Information Hiding Workshop 1999: 302-317

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