Color Image Appearance Model Applied to Printing of Watermarked Images

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Abstract

Several authors have proposed the application of perceptual models to the watermarking of still images. Most of these methods use a luminance based model that do not take into account the effect of the output process on image quality. For example, in printing the same digital image will appear very different if it is printed on newsprint, compared to printing on high quality gloss paper.

The color image appearance model we described has been used to obtain approximately equal watermark visibility across an image. For a given visibility, this allows a higher watermark signal to be applied to an image. The watermark signal strength has also been corrected for images output on different types of paper stock, to obtain approximately the same visibility level.

1. Introduction

Several authors have proposed the application of perceptual models to the watermarking of still images (see [1] and [2] for a review of proposed methods, and [3] for CMYK printed images). Most of these methods use a luminance based model that do not take into account the effect of the output process on image quality. For example, the same digital image will appear very different if it is printed on newsprint, compared to printing on high quality gloss paper.

A color image appearance model is described for a print that is being watermarked, and calculates a grayscale visibility difference map. The visibility difference map is used to equalize the visibility of the watermark across the image, resulting in the maximum watermark signal at any visibility level. In general the visibility metric tracks signal robustness, so this process optimizes signal robustness for the target visibility.

The color image appearance model is based on the Watson metric, together with a model of the print process that is applied to the input images. Many factors affect the image quality of offset printed images. The major factor that affects the print watermark visibility is the luminance range of the paper stock. The print model is used to automatically obtain the required visibility level for a watermark on characterized paper stocks.

2. Color Image Appearance Model and Watermark Workflow

The color image appearance model consists of 3 main components as shown in Figure 1.

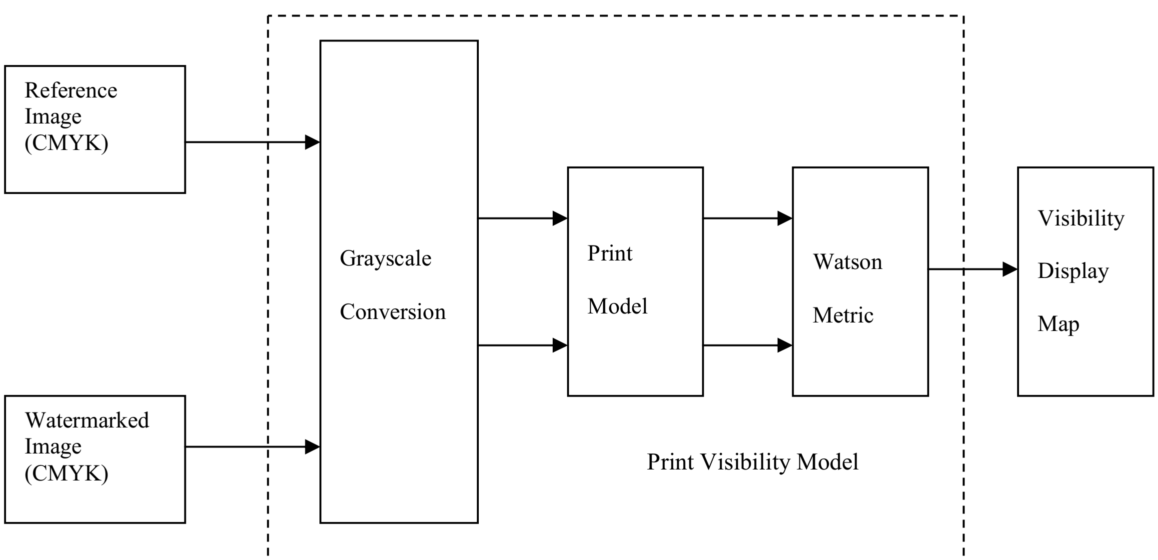

Figure 1: Color Image Appearance Model for Print

The reference and watermarked images are passed through a grayscale conversion going from CMYK to luminance. The luminance images are passed through a print model to correct for paper stock that converts from digital luminance to measured luminance (see Figure 5), and the two images are then compared in the Watson metric (see [4]), to produce an output visibility display map as a grayscale image.

The color image appearance model generates a visibility display map that is used to create a grayscale mask that controls the watermark strength to obtain approximately uniform visibility. A marked image with the required level of visibility can be produced, on different types of print media from a heavy gloss paper stock to newsprint. The process of embedding a watermark in a CMYK image for print makes use of an original image along with a grayscale mask, calculated by the color image appearance model, as shown in Figure 2.

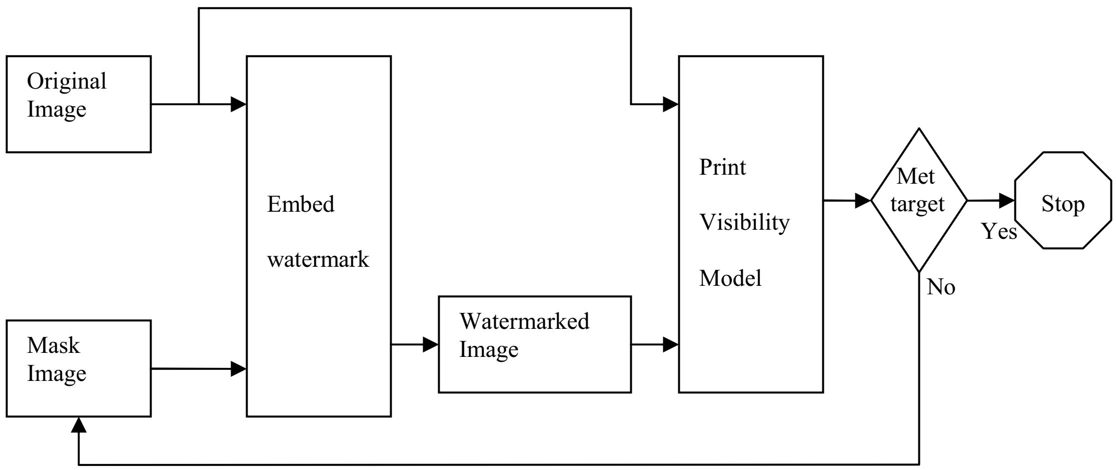

Figure 2: Workflow for Iterative Embedding

The visibility display map from the print visibility model is blurred to reduce 8 by 8 blocking artifacts from the Watson metric calculation. The departure of the metric from the required visibility level is used to adjust the mask image up and down. The mask controls the amount of watermark signal being embedded in different parts of the image. This process continues until a visibility "goal" is reached, and the visibility map is approximately constant across the entire image (see Figure 3).

The embedding software automatically determines the maximum watermark signal level that can be inserted while achieving the required visibility on the different paper stock. The signal level is also adjusted to compensate for the different types of image content, and the effect of watermark resolution.

3. Results

The model described in Section 2, was used to calculate the visibility of a watermark added to an image. The visibility display map was used to iteratively adjust the watermark strength, until the target level of visibility was achieved within the required tolerance ~1 JND (Just Noticeable Difference) for more than 90% of the whole image (see Figure 3). Areas on the visibility map which have a color lighter than mid-gray have a higher visibility than the target, and areas darker than mid-gray have lower visibility than the target. The steps in visibility shown in Figure 3 are ~ 1 JND visibility increments.

This allows the maximum watermark signal strength for a given level of visibility to be inserted. If the visibility is not approximately constant across an image, the watermark strength will be limited to the strength at which a significant area of the image exceeds the target visibility level. For example in iteration 0 (Figure 3), the overall watermark strength would have to be reduced to avoid the visibility in the sky region being objectionable if the target is 3 JND. The overall strength reduction to obtain 3 JND in the sky is shown in 'Overall Strength Reduction'. A higher watermark signal is added in iteration 1 than an overall watermark strength reduction, since the reduction of signal in the sky is partly offset by an increase in the signal in the trees.

A small region of the image is magnified in Figure 4 (shown by dashed box on 'Original Image' in Figure 3), showing the average Watson metric as a JND value in a 128 by 128 pixel area.

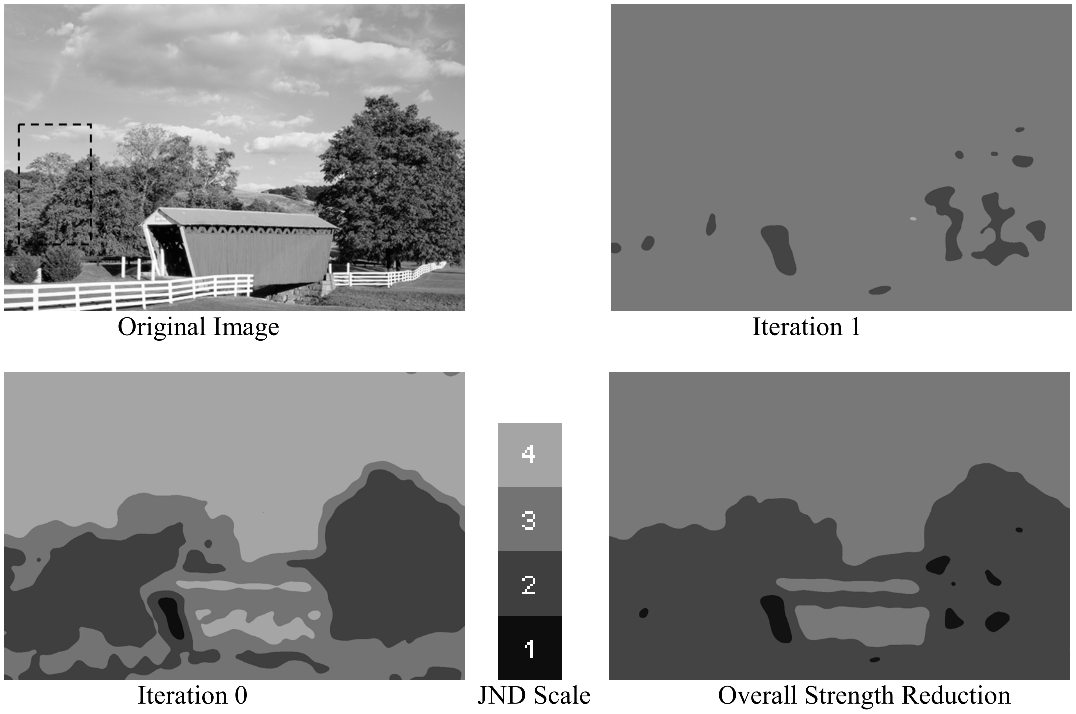

Figure 3: Visibility Display Map

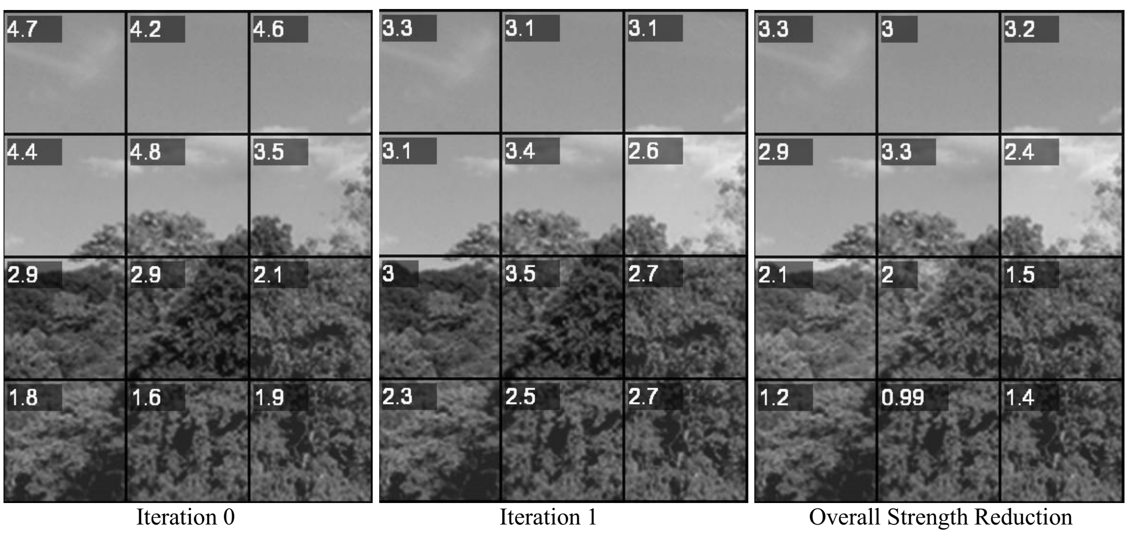

Figure 4: Average Watson Metric

Since the Watson metric values are a good indicator of watermark signal strength, these values were summed over the whole image for 'iteration 1' and 'overall strength reduction'. An increase in the summed Watson metric of 35% was measured in the 'iteration 1' case, implying about 35% more watermark signal was added for the same visibility.

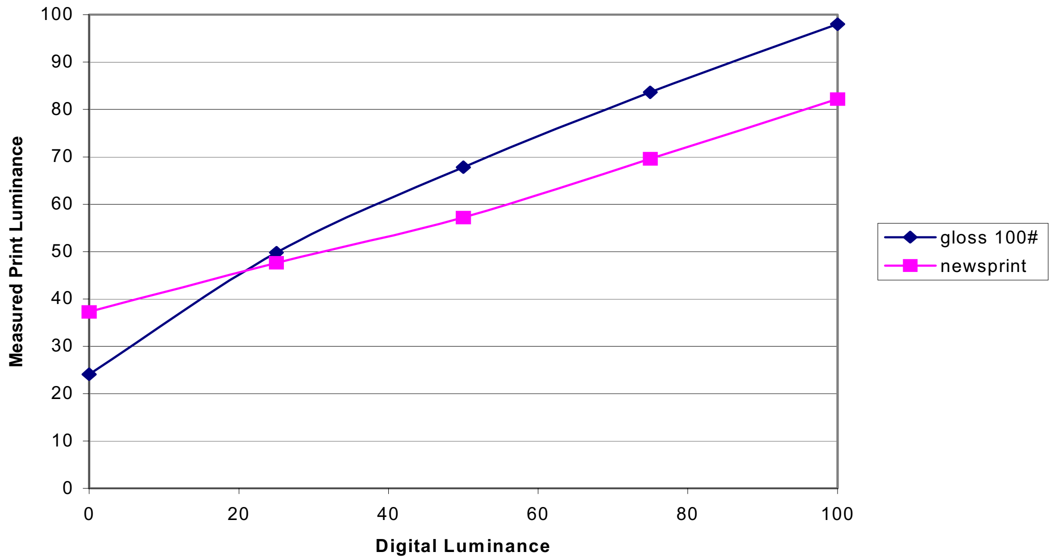

Figure 5: Tonal Range Comparison on Different Paper Stock

The tonal range for the two paper stocks is shown in Figure 5 above. By using the gloss 100 digital to print luminance mapping the visibility model was used to calculate a uniform visibility watermark for an image which was output to 100 pound gloss paper. The newsprint mapping was then used in the visibility model to calculate an image watermarked at a higher strength that has the same visibility output to newsprint. The two pairs of images were compared and the visibility difference between the original and marked image on 100 pound gloss and newsprint was found to be about the same.

4. Conclusions

The color image appearance model we described has been used to obtain approximately equal watermark visibility across an image. The watermark signal strength has been corrected for images output on different types of paper stock, to obtain approximately the same visibility.

Controlling the watermark signal strength with this model, allows a more consistent signal level to be added to the image which takes into account the following factors:
a) Image content
b) Signal loss due to the luminance range of the paper stock.
For a given visibility, this allows a higher watermark signal to be applied to an image.

5. Future Work

Images in this study were printed on different paper stock using an inkjet printer. It is planned to extend the results to offset printing on different paper stocks.

The model we have described can be altered for other physical output processes such as a screen display by replacing the 'Print Model' component in Figure 1 with a 'Screen Display Model'. This would allow the watermark visibility to be specified for screen display images.

The print visibility model could also be extended to include an attention model which would allow a larger watermark signal to be placed in the background regions of an image [5].

6. References

[1] Raymond B.Wolfgang, Christine I. Podilchuk and Edward J.Delp, 'Perceptual Watermarks for Digital Images and Video', Proceedings of the IEEE Vol 87, No. 7, July 1999
[2] Ingemar J. Cox, Matthew L. Miller and Jeffrey A. Bloom, 'Digital Watermarking', pp. 222-240, Academic Press 2002
[3] Brett T. Hannigan, Alastair Reed, Brett Bradley, "Digital watermarking using improved human visual system model," *SPIE Electronic Image 2001*
[4] Andrew B.Watson, US patent 5,629,780
[5] Wil Osberger, Tektronix, personal communication

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