An Innovative Pixel Scoring Method for Watermarking of Binary Document Images

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ABSTRACT
In order to embed a watermark into a binary document image, some subset of image pixels needs to be modified. This modification will cause a document image distortion. Careful selection of image pixels can make distortion appear less visible. We propose a new binary document image pixel scoring method, the Structural Distortion Measure, whose objective is to identify image pixels whose modification, as part of a watermark embedding process, will minimize document image visible distortion.

Keywords: Binary document images, Image watermarking, Visible image distortion, Structural distortion measure

1. INTRODUCTION

In our society, documents represent a primary form of written communication, and large volumes are exchanged daily. Document recipients may want to be able to authenticate documents and digital watermarking can be specifically used for that purpose. While many techniques have been proposed for watermarking of gray scale and color images, those techniques cannot be directly applied the binary images for a number of reasons. Gray scale and color image pixels take a wide range of values, and watermarking techniques typically make small modifications to the color or brightness values of the selected set of pixels without causing visually noticeable image distortion [7].

Binary images have only two distinct pixel color values. Therefore, it is not possible to make a small modification of those values, the approach that works so successfully with gray scale or color images. It is also not possible to apply a frequency domain approach, such as a spread spectrum embedding, to binary document image watermarking because of the need for post-embedding binarization of a watermarked image. Post-embedding binarization, to ensure that the marked image is still a two-color image, has been shown to create a perceptible distortion along the black-white boundaries and to disturb the embedded watermark to the point of removing it completely [1][6].

Document images are scanned representations of two-color documents, such as legal documents, birth certificates, digital books, engineering maps, architectural drawings, road maps, music scores, etc. This paper will focus on how to make invisible modifications of document images.

Watermarking techniques for binary document images have some special requirements For example, it is not possible to arbitrarily choose the set of pixels to modify in binary document images, because changing even a single white pixel to black in an all white section of a binary document image will produce a visible image distortion. This can easily be seen in Figure 1, which shows three images, the original image and two modified versions of the original image. Both modified versions have the same number of pixels changed. Modifications are made randomly in the Modified Image 1, and the Modified Image 2 is created from the original image by flipping two rows of white pixels adjacent to the black pixels on the two horizontal bars. Even though both modified versions have the same number of changed pixels, the distortion appears more pronounced in the Modified Image 1 where the pixels have been randomly selected for modification. This also demonstrates that the number of modified pixels in an image is not a good measure of visible image distortion, and that careful selection of pixel candidates for modification minimizes visible image distortion.

Figure 1. Original binary image and two modified versions of the original image with the same number of modified pixels.

Any modification of binary document image pixels from black to white and from white to black will cause image distortion. The objective should be to select and modify only those pixels whose modification will cause image distortion that is visually the least perceptible.

In this paper, we propose a new pixel scoring method called the Structural Distortion Measure (SDM), designed to score binary document image pixels in order to identify the best pixel candidates for modification.

2. DISTORTION MEASURE

There are a number of ways a visible distortion of a binary document image can be assessed. The methods can broadly be divided into two categories: subjective and objective. Subjective methods are based on using human observers, and they depend on subjective perceptions of the people involved in the distortion evaluation experiments. Subjective methods produce accurate results, but they are difficult to replicate and hard to incorporate into an algorithm.

The traditional objective distortion metrics that are frequently used include the Mean Squared Error (MSE) and Peak Signal-to-Noise Ratio (PSNR). The MSE is one of the simplest distortion measures. It examines the magnitude of difference between two images, pixel by pixel, in the form of the squared error of a pair of pixel intensities. For binary images, the MSE actually represents the number of differences between two images. The PSNR is derived from MSE, and therefore, these two distortion measures are essentially equivalent.

The problem with these distortion measures is that they do not provide a good measure of visible distortion. A good demonstration of that is exemplified by Figure 1. Both second and third images have been created from the first image by modifying the same number of pixels, which means that they both have the same MSE. However, the distortions perceived by the human eye are quite different for the second and third images. The reason is that MSE measures distortion based on the state of individual pixels, without considering any structural information. Since the main function of the human visual system (HVS) is to extract structural information from the viewing field, a distortion metric which takes into consideration structural distortion, will provide a better approximation of visible image distortion [4].

The Distance-Reciprocal Distortion Measure (DRDM) correlates better with visually perceived distortion in binary images than MSE [5]. The DRDM is an objective measure of visible distortion between two binary document images. It is designed based on an assumption that a distance between two pixels within an image plays an important role in how the HVS perceives the mutual interference of those two pixels. Modification of pixels is more visible if they are closer to the area of viewer's focus. The closer the two pixels are, the more sensitive the HVS is to the change of one pixel when focusing on the other. Additionally, when observing the eight neighbors of a pixel, the diagonal neighbors are considered to be farther away from the pixel than its horizontal and vertical neighbors. Consequently, when focusing on a specific pixel, modifications of its diagonal neighbors are expected to have less visual effect than modifications of its horizontal and vertical neighbors.

We use the DRDM as an ultimate measure of visible distortion caused by embedding watermarks into binary images, to evaluate suitability of the SDM as the method for selection of modification candidate pixels in binary document images.

3. STRUCTURAL DISTORTION MEASURE

The Structural Distortion Measure is an objective metric designed to identify image pixels whose modification will cause the minimum visible document image distortion. The SDM takes into consideration the $m \times m$, m=3,5,7,… neighborhood of an individual pixel, and it calculates the pixel's modification score in that neighborhood. A modification score is a number between 0 and 1, where modification of a pixel with the highest score is expected to introduce the minimum visible image distortion. The SDM corresponds well with the subjective methods because it favors pixel modifications that contribute to the creation of more compact structures or objects in a local neighborhood.

The SDM scoring method is based on the reciprocal distance matrix D_m, for an $m \times m$ neighborhood. The SDM for an individual modification candidate pixel is calculated in the $m \times m$ neighborhood N_m of the candidate pixel, cp, as a normalized correlation between $XOR(cp, N_m)$ and D_m:

$$SDM_{cp} = \frac{(cp\ XOR\ N_m) \bullet D_m}{|D_m|}.$$

Pixel candidates for modification in a binary document image are not selected randomly. They are selected from the set of boundary pixels between white and black areas. The set of pixel candidates includes the white pixels, which have black pixel neighbors, and the black pixels, which have white pixel neighbors. The value of the candidate pixel, cp, is exclusively *OR*ed with pixels in its neighborhood, N_m, to ensure that correlation calculation depends only on the neighboring pixels that have different color than cp. In other words, pixels which have more neighbors of the opposite color are better candidates for modification than pixels which have more neighbors of the same color.

4. AN EMPIRICAL EVALUATION OF SDM PIXEL SCORING

We evaluate performance of the SDM pixel scoring method empirically by embedding the OK and Biz logos as watermarks into the set of eight binary document images, scanned at 200 dpi [3]. Watermarks are embedded by dividing the image into blocks and modifying some subset of pixels in each block in order to enforce a certain block feature [2]. Pixels are selected for modification based on two different pixel scoring methods, the SDM we introduced in this paper and MWLUT (Min Wu's Look Up Table-based scoring) [8][9].

After embedding watermarks into binary images based on two different pixel selection methods, the resulting image distortion is calculated using a Distance-Reciprocal Distortion Measure (DRDM) [5].

Data embedding is based on partitioning an image into 64×64 blocks and hiding one bit per block using the uniform quantization approach. The size of all CCITT test images is 2376×1728, so that with 64×64 partitioning blocks, the embedding capacity of this watermarking scheme is 999 bits. Two 910-bit logo images, the Biz and OK, are embedded as watermarks. Image pixels are randomly permuted to ensure a more even distribution of modification candidate pixels. The candidate pixels to be modified are selected based on the SDM scores calculated in the 3×3 pixel neighborhood in one case, and based on the MWLUT scores stored in a pre-calculated lookup table of 512 entries in the other case. The MWLUT lookup table contains the flipping scores for all possible 3×3 patterns. The overall image distortion caused by watermark embedding is measured using both MSE and DRDM. The DRDM uses 7×7 weight matrix W_7.

The experiments showed that both watermarking embedding schemes modified approximately the same number of image pixels, and DRDM numbers were very small and close to each other for both watermarking schemes. In order to force some difference we embedded the 910-bit Biz logo message as a robust watermark using quantization step $Q=22$. More robust embedding requires more image pixels to be modified, so that two different pixel scoring methods should result in different levels of visible distortion in watermarked images.

Table 1 provides image distortion information measured using MSE and DRDM for watermark embedding schemes based on MWLUT and SDM pixels scoring using uniform quantization with the quantization step $Q=22$. The MSE numbers indicate that both pixel scoring methods have modified the same number of pixels to embed the Biz logo message robustly into CCITT7. The DRDM measure is at least 5 times larger when embedding is done using the MWLUT scoring, indicating that the Biz embedding will create less visible distortion when pixels are modified based on their SDM scores.

Table 1. Comparison of image distortion results measured using MSE and DRDM between watermark embedding schemes based on MWLUT pixel scoring and SDM pixel scoring.

SCHEMES	MSE Measure	DRDM Measure
SDM	4513	0.0066
MWLUT	4513	0.0206

In Figure 2, image pixels are modified based on their SDM score in one case and based on the MWLUT in the other case. The DRDM measure suggests that distortion is more visible when embedding is done based on the MWLUT scores. For example, look closely to the R part of the zoomed in portion of the watermarked document. The embedding based on SDM scoring appears to be more compact. Figure 2 confirms that embedding based on the SDM pixel scoring results in watermarked images with less visible distortion than embedding based on the MWLUT scores. This visual inspection of watermarked images supports DRDM visible distortion results presented in Table 1.

5. CONCLUSION

In conclusion, both pixel scoring methods, the SDM and the MWLUT, identify a set of modification candidate pixels whose modification causes little visible image distortion. When watermark embedding requires a large number of image pixels to be modified, the SDM-based scoring identifies the better set of modification candidate pixels than MWLUT scoring. Consequently, watermark embedding based on the SDM pixels scoring creates fewer artifacts and results in smaller visible distortion of watermarked images. Additionally, the SDM scoring has an advantage over the MWLUT scoring because it does not depend on a pre-calculated lookup table. It is computationally simple enough so that the lookup table is not necessary, and the pixel modification scores can be calculated for each pixel when and as needed. This also means that the SDM based scoring can be easily extended to larger neighborhoods, such as 5×5 or 7×7, unlike any

LUT-based scoring including the MWLUT, which would require very large lookup table with 32,768K entries in order to support scoring pixels based on their 5×5 neighborhoods, for example.

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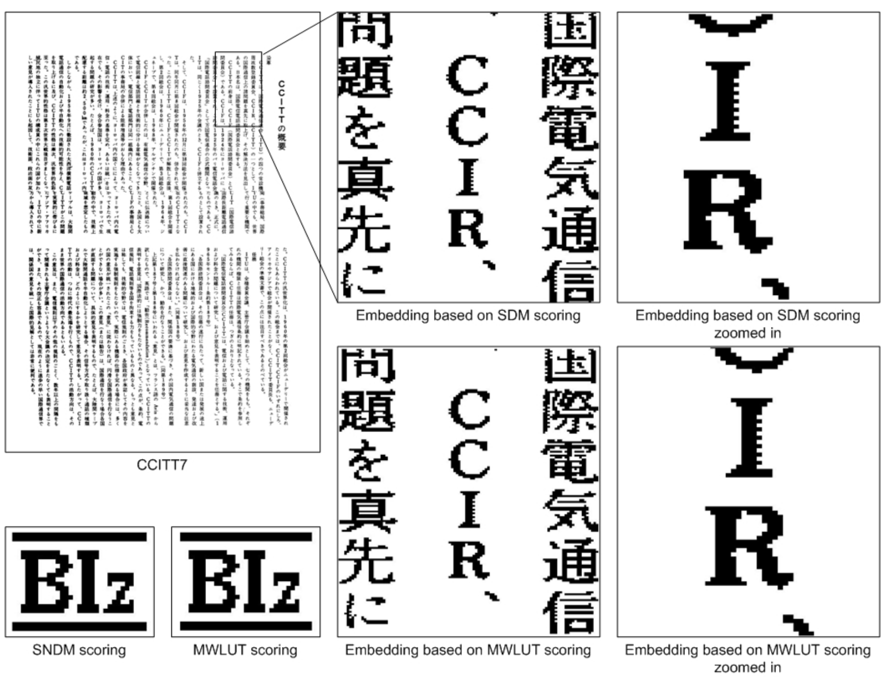

Figure 2. The result of embedding the Biz logo as a robust message using uniform quantization with step size Q=22.