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An Innovative Pixel Scoring Method for Watermarking of Binary Document Images

Edin Muharemagic, IBM Corporation, Boca Raton, Florida, USA

Borko Furht, Florida Atlantic University, Boca Raton, Florida, USA

For correspondence: Borko Furht

Department of Computer Science and Engineering

Florida Atlantic University, 777 Glades Road

Boca Raton, FL 33431-0991, U.S.A.

Tel: 561-297-3486

Fax: 561-297-2800

E-mail: borko@cse.fau.edu

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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 [8].

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][7].

Binary images can be divided into two broad categories, *half-tone* and *document* images. This classification is based on characteristics of distribution of image pixels, which in turn depends on how an image is created. Half-tone images are created from gray scale images using *half-toning*, a process which takes a gray scale image and converts it into a binary image so that the original and the half-tone image appear similar when observed from a distance. Half-tone images are created for simplified processing or printing, and they can be found in printed materials, such as books, magazines, newspapers, and printer outputs. 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 [5]. 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.

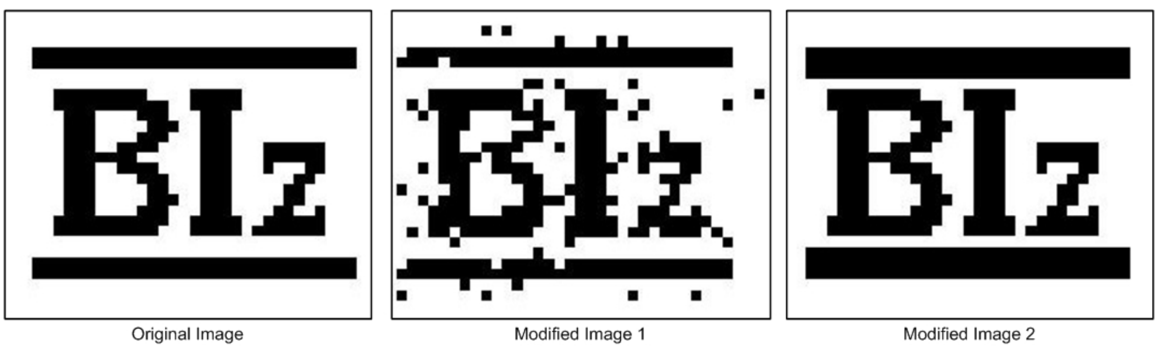

Figure 1. Original binary image and two modified versions of the original image with the same number of modified pixels. This demonstrates that the number of modified pixels in an image is not a good measure of visible image distortion. Distortion is much more visible on the Modified Image 1 than on the Modified Image 2.

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. The selection of best candidates for modification cannot be based on the models of the HVS built for natural images because the perception of distortion in binary document images is different than perception of distortion in natural images [6]. One reason for the difference is that, in any particular language, people know very well what a certain symbol should look like. If modification of binary document image pixels changes the structural form of those symbols, the resulting binary document distortion could be very visually disturbing to a casual observer.

In this paper we propose a new distortion metric called the Structural Distortion Measure (SDM). It is an objective metric designed for scoring of binary document image pixels in order to identify the best pixel candidates for modification, to be used as part of a watermark embedding process. The best candidates are those pixels whose modification will cause the minimum visible distortion.

The rest of this paper is organized as follows. We first introduce various distortion measures which can be used for binary document images, and we identify the one which provides good approximation of visible image distortion. Then we describe the specifics of the structural distortion measure. After that we present results of an empirical evaluation of SDM-based binary document image scoring. We close this paper with some concluding remarks regarding the merits of the SDM.

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, and derives its measure as:

$$MSE = \sum_{i=1}^{N}\sum_{j=1}^{M}(a_{i,j} - b_{i,j})^2, \tag{1}$$

where a and b represent two images of resolution $N \times M$, and $a_{i,j}$ and $b_{i,j}$ are the intensities of the pixel *(i,j)* in a and b respectively.

The corresponding PSNR is defined as:

$$PSNR(dB) = 10\log_{10}\frac{P^2}{MSE}, \tag{2}$$

where P is the maximum pixel intensity. For example, P is 255 for an 8-bit image, and it is 1 for a binary image.

Since PSNR is based on the MSE, 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 and PSNR. However, the distortions perceived by the human eye are quite different for the second and third images. The reason is that both MSE and PSNR measure distortion based on the state of individual pixels, without considering any structural information.

For binary images, the MSE actually represents the number of differences between two images, and the large number of different pixels does not always result in a large structural difference between two images. 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 and PSNR [6]. 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.

The DRDM method measures distortion between two binary images, a and b, using a normalized weight matrix W_m of size $m \times m$, where m=3,5,7…, with each of its weights representing reciprocal value of the distance measured from the center pixel. The distortion is calculated as:

$$d = \frac{\sum d_k}{K}, \tag{3}$$

where K is defined as the number of non-uniform (not all black or all white pixels) 8×8 blocks in the image a, and d_k is a local distortion calculated in the $m \times m$ neighborhood for each pixel of difference between image a and image b, using the following formula:

$$d_k = \sum_{mxm} [| a_m - b_m | \times W_m]. \tag{4}$$

The DRDM provides a distortion measure, which correlates well with subjective methods, and hence it is superior to the MSE and PSNR [6].

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 the best pixel candidates for modification, the 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. An example of the D_3 matrix is shown in Figure 2.

0.7071	1.0	0.7071
1.0	0	1.0
0.7071	1.0	0.7071

Figure 2. Reciprocal 3x3 Euclidian distance matrix.

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:

$$SDM_{cp} = \frac{(cp\ XOR\ N_m) \bullet D_m}{|D_m|}. \tag{5}$$

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.

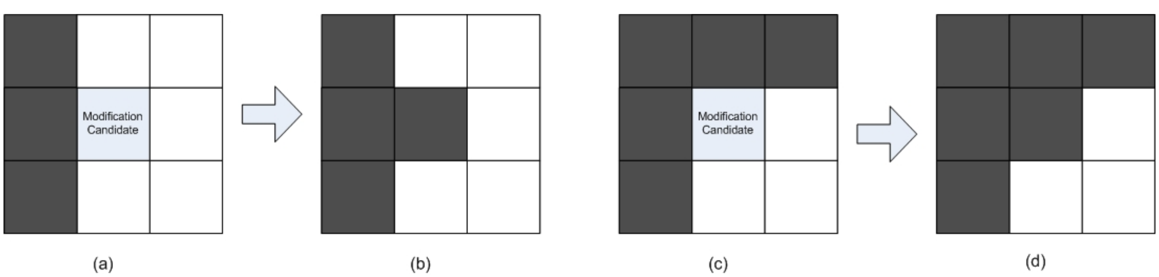

Figure 3 shows an example of two modification candidates in a *3×3* neighborhood. The first modification candidate is a white pixel with three neighboring black pixels as depicted in the image (a), and the second one is a white pixel with five neighboring black pixels, as depicted in the image (c). The first modification candidate has SDM=0.3536 and the second one has SDM=0.6063. If an image block has two 3×3 patterns in it, (a) and (c), it will have at least two pixel candidates for modification. However, if only one pixel needs to be modified, then, based on the respective pixel modification scores, the (c) candidate should be selected for modification because modification of the (c) candidate pixel is expected to cause smaller visually perceptible distortion than modification of the (a) candidate pixel. The images (b) and (d) show how the respective neighborhoods look, after both candidates have been modified.

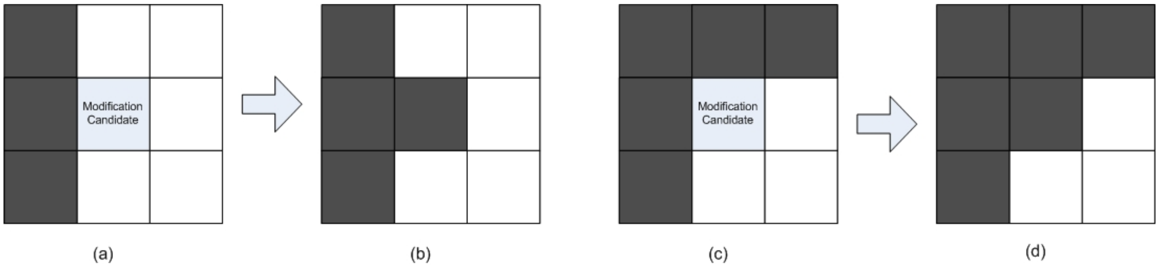

Figure 3. Images (a) and (c) represent two patterns in a 3x3 neighborhood. The modification candidate pixel is the central pixel in the neighborhood. The two images (b) and (d) represent new patterns created by modifying the modification candidate pixels.

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 CCITT images given in

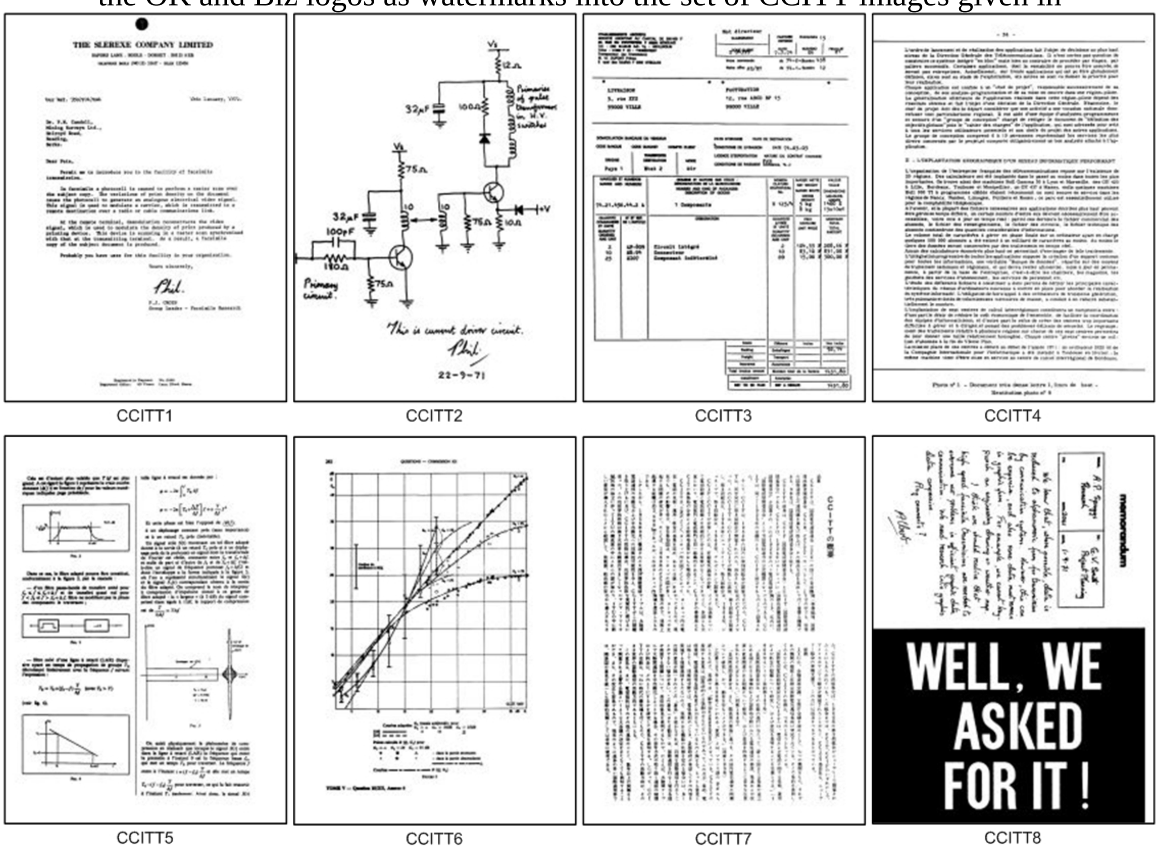

Figure 4. These eight CCITT binary document images, scanned at 200 dpi, characterize a good representative set of binary document images [3]. They include printed text documents using English, French and Chinese alphabet symbols, handwriting, hand drawing, tables, graphs, and combination of text and graphs. 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) [9][10][11].

The MWLUT method scores modification candidate pixels based on a scoring table created by analyzing all possible combinations of black and white pixels in a 3×3 neighborhood. The score is assigned to every one of 512 possible patterns, based on a subjective estimate of the level of visually perceptible distortion that a modification of the center pixels of a specific 3×3 pattern will create. The 3×3 patterns are analyzed once. The assigned scores are stored in a look-up table and used by a data embedding algorithm to identify pixels whose modification will cause minimum visible distortion. The look-up table score is keyed based on the corresponding numerical value that the pixel's 3×3 neighborhood maps into. While the analysis of black and white patterns and the creation of a look-up table can be done for 3×3 patterns, the 3×3 neighborhood could be too small a neighborhood for an accurate assessment of visual distortion caused by modification of the center pixel. The scoring based on an analysis of larger patterns (i.e. 5×5, or 7×7) may produce better results, but an analysis of larger patterns is much more extensive and complicated, requiring the use of prohibitively large look-up tables.

After embedding watermarks into binary images based on two different pixel selection methods, the resulting image distortion is calculated using two different distortion metrics, a Peak Signal-To-Noise Ratio (PSNR), and a Distance-Reciprocal Distortion Measure (DRDM) [6]. This experiment is illustrated in

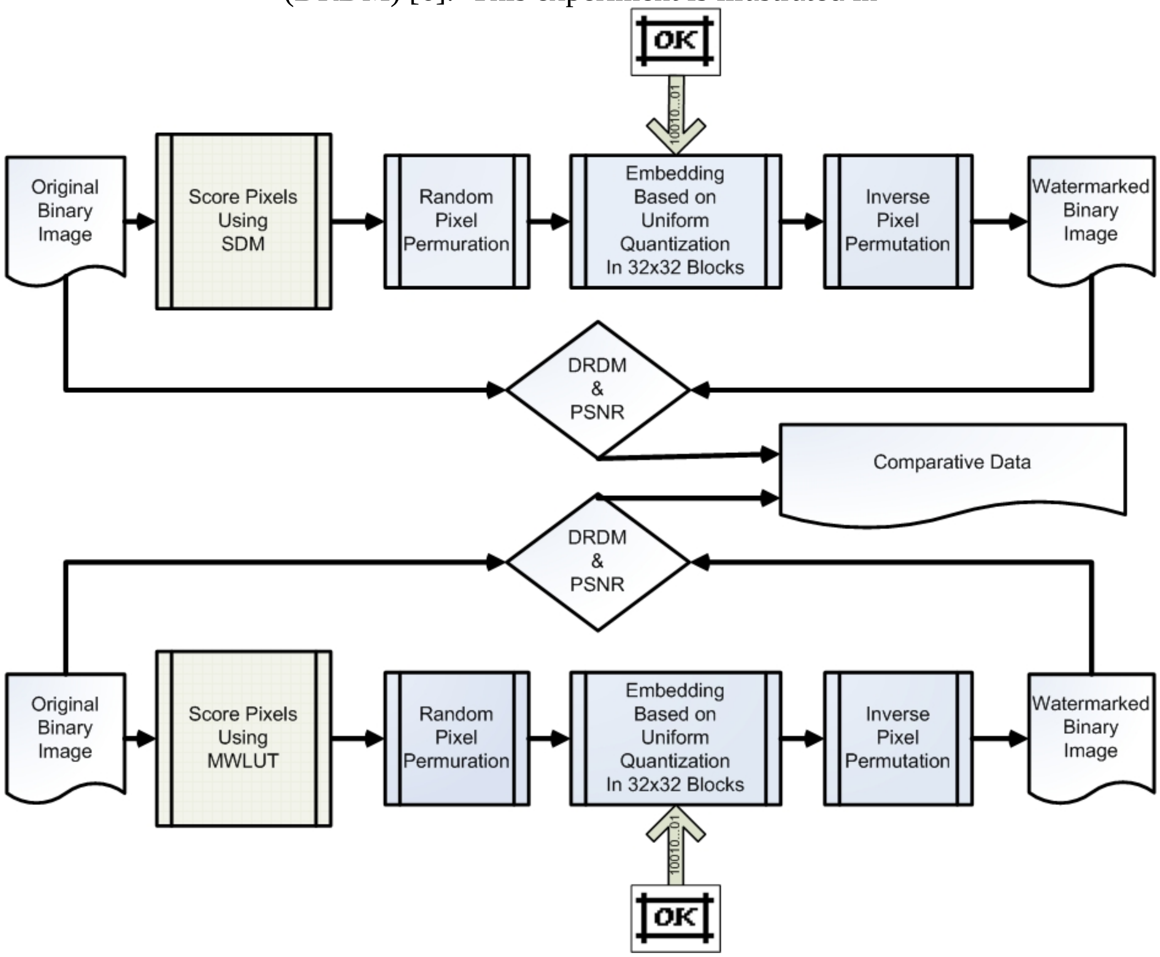

Figure 5.

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 PSNR and DRDM. The DRDM uses 7×7 weight matrix W_7.

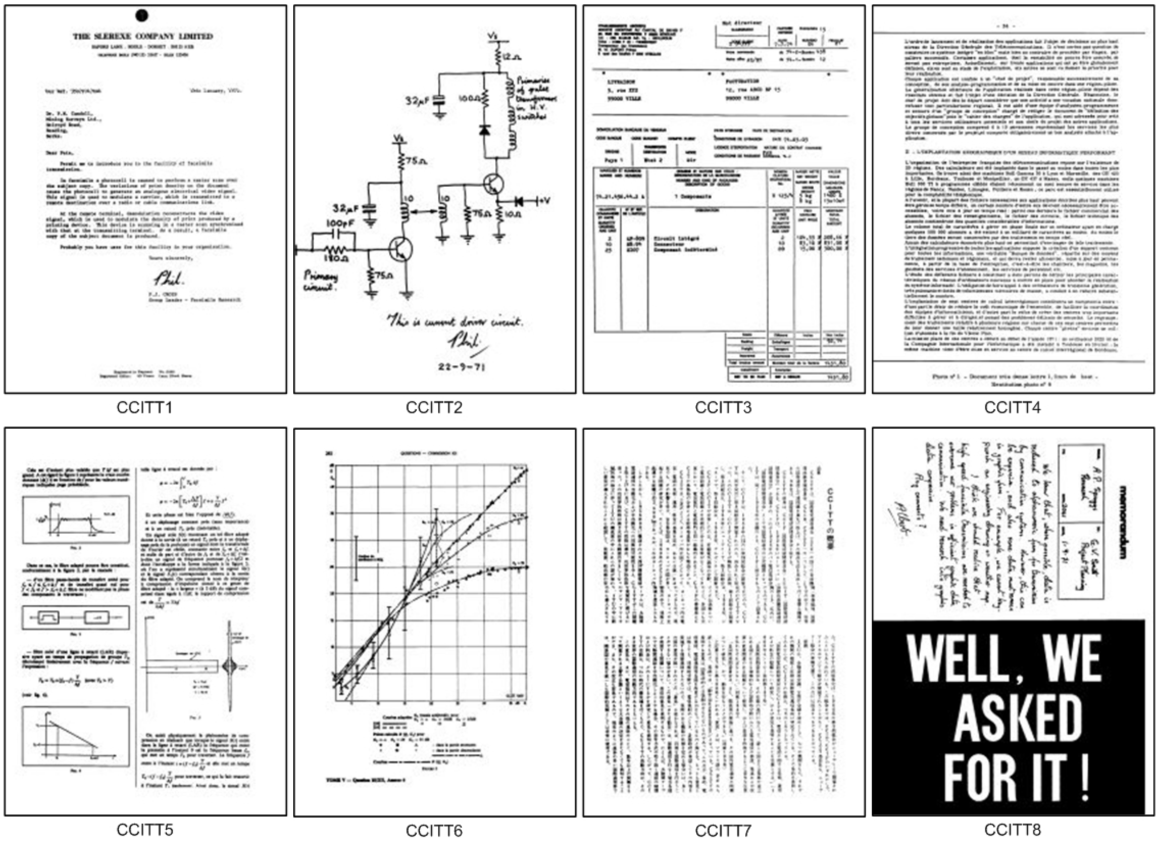

Figure 4. Eight 2376x1728 binary document images, CCITT1-CCITT8, scanned at 200 dpi.

Table 1 provides a summary of image distortion results calculated using PSNR and DRDM after embedding the OK logo as a fragile mark into the set of CCITT images. The OK logo image is embedded using the uniform quantization with the quantization step $Q=2$. The PSNR numbers calculated for the two watermarking schemes using the two pixel scoring methods are either the same or very close to each other. Since PSNR provides a measure of the number of modified pixels in a binary image, both watermark embedding methods modify approximately the same number of pixels in order to embed the 910-bit OK logo message. The number of pixels, which are modified to embed the OK logo as a fragile mark into the set of CCITT images, is provided in Table 2. The table shows that the number of modified pixels is approximately equal to a one half of the number of message bits. In other words, in order to embed a 910-bit message, approximately one half of the image partitioning blocks do not need to be modified at all.

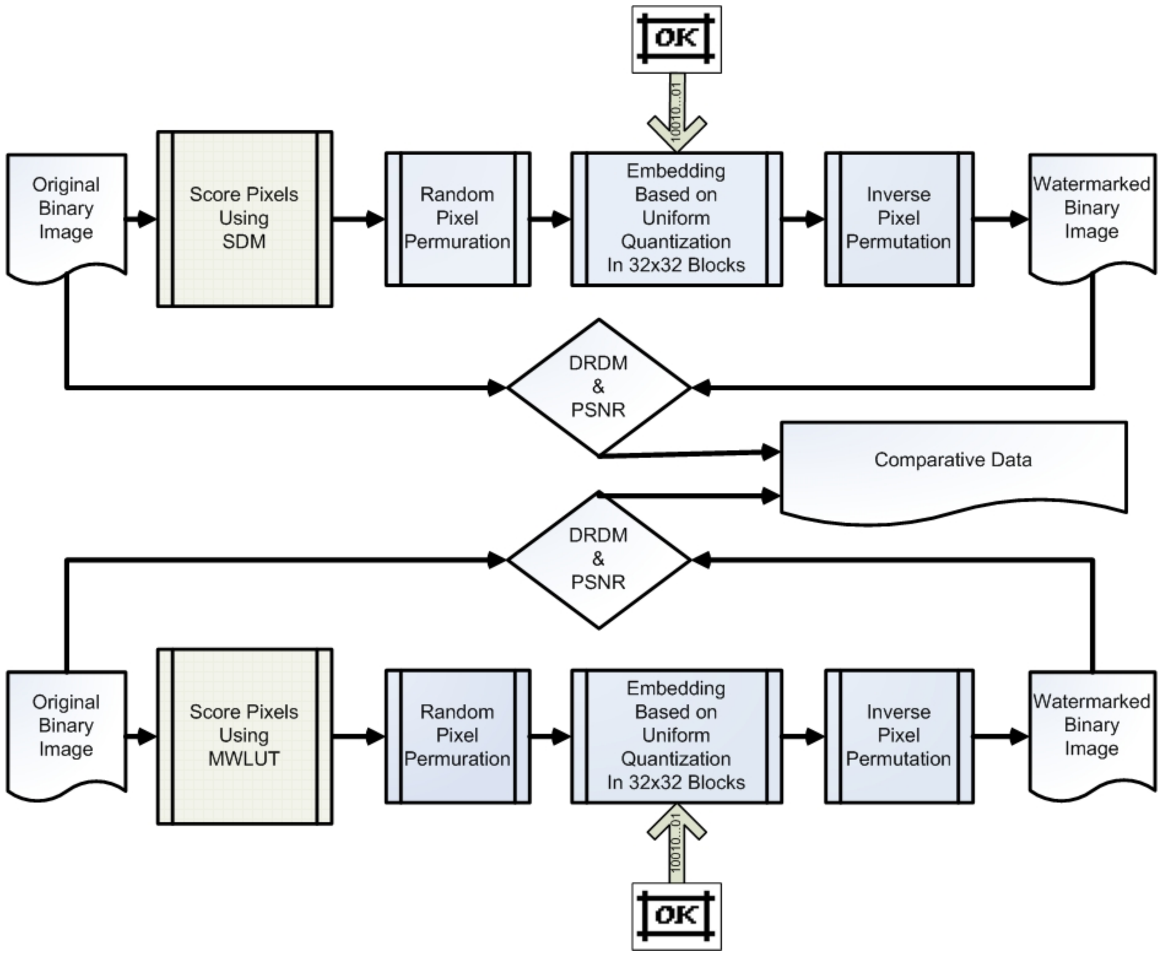

Figure 5. The two watermark embedding schemes differ only in how the modification candidate pixels are scored. One scheme uses the SDM scoring and the other one the MWLUT scoring.

The PSNR numbers demonstrate that both watermark embedding schemes modify approximately the same number of image pixels. However, those numbers do not give any indication about whether image pixel modifications create visible image distortions. The DRDM represents a measure of visually perceptible image distortion. The DRDM numbers listed in Table 1 are very small. The values indicate very small visually perceptible distortion of watermarked documents, and consequently a very good quality of watermarked document images. In general, watermarked images with DRDM values below 0.2 have a good quality and very little visible distortion [6]. Accordingly, the watermarked images with DRDM numbers close to zero have no visible distortion.

Table 1. Comparison of image distortion results measured using PSNR and DRDM between watermark embedding schemes based on the MWLUT pixel scoring and the SNDM pixel scoring. In both cases, the 910-bit OK logo message was embedded into the set of CCITT images as a fragile mark.

	1	2	3	4	5	6	7	8
PSNR (SDM)	27.03	26.69	26.88	26.92	26.91	26.98	26.89	27.06
PSNRMWLUT)	27.06	26.91	26.88	26.92	26.91	27.02	26.89	27.06
DRDM(SDM)	0.006	0.009	0.007	0.001	0.004	0.009	0.011	0.003
DRDM(MWLUT)	0.029	0.036	0.003	0.001	0.004	0.016	0.004	0.010

An attempt to demonstrate that watermarked images have no visible artifacts can be found in Figure 6 where the original CCITT1 image is shown side by side with its watermarked version where pixels were modified based on their SDM and MWLUT scores. Both pixel scoring methods obviously identified good modification candidates, so that a naked eye cannot see the difference between the original and the watermarked image.

Table 2. The number of pixels modified as part of embedding the OK logo as a fragile mark.

	1	2	3	4	5	6	7	8
MSE(SDM)	505	467	488	492	491	499	489	508
MSE(MWLUT)	508	491	488	492	491	503	489	508

A subset of modified pixels is shown in Figure 7. The watermarked images are represented as gray scale images to make it easier to see which pixels have been modified as part of the watermark embedding process. Circles were used to mark the modification areas, and the 5×5 neighborhood of the modified pixels was marked with the lighter shade of gray. The modified pixels are either shown as black or white dots.

This experiment shows that embedding a 910-bit message as a fragile mark into the set CCITT images, where image pixels are modified based on their SDM score, creates no visible image distortion, and the resulting quality of the watermarked image is comparable with the quality of the watermarked image where image pixels are modified based on their MWLUT scores.

Since embedding a 910-bit message as a fragile mark into the set of CCITT images results in modification of a very small fraction of image pixels (e.g. 508 out of 2376×1728, or 0.012% in the CCITT1 case), the next step was to evaluate visible image distortion caused by watermark embedding which results in modification of a larger number of pixels. To achieve that goal, this experiment was repeated with the 910-bit Biz logo message embedded as a robust watermark using the uniform quantization with the quantization step $Q=10$.

Even after embedding the 910-bit Biz logo message with the quantization step $Q=10$, the calculated DRDM results demonstrated that both pixel scoring methods, the SDM and

MWLUT, select pixels for modifications which do not create visible image distortions. Obviously, it is important to find a way to increase the number of modified pixels, because as the number of pixel modifications increases the resulting image distortion should become more visible.

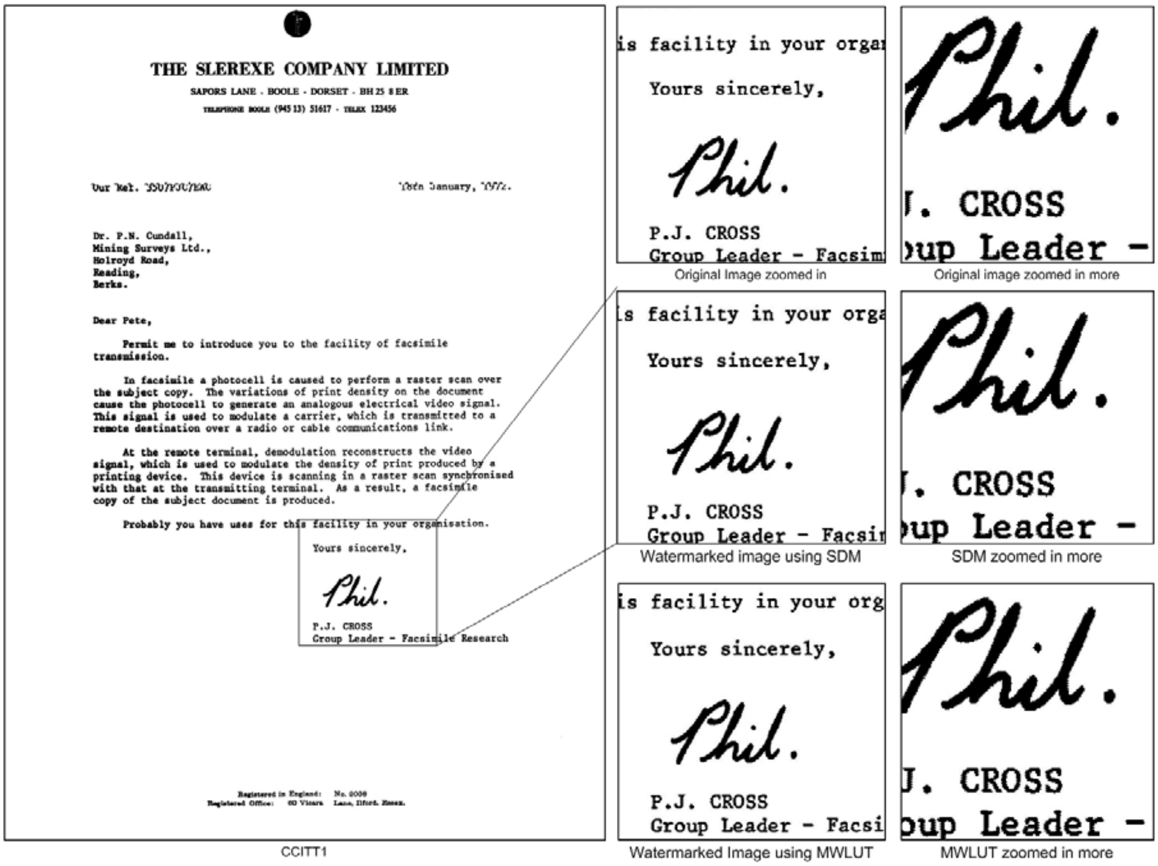

Figure 6. CCITT1 document is shown before and after watermark embedding. Document image pixels are selected for modification based on their SDM and MWLUT scores.

The number of pixel modifications can be increased by making the embedded Biz logo more robust, and this is achieved by increasing the quantization step *Q*. The next experiment was designed to achieve that objective. It is very similar to the previous one. The only difference is that this time, the 910-bit Biz logo message is embedded more robustly with the quantization step *Q=22*. More robust embedding will require more image pixels to be modified, so that two different pixel scoring methods should result in different levels of visible distortion in watermarked images.

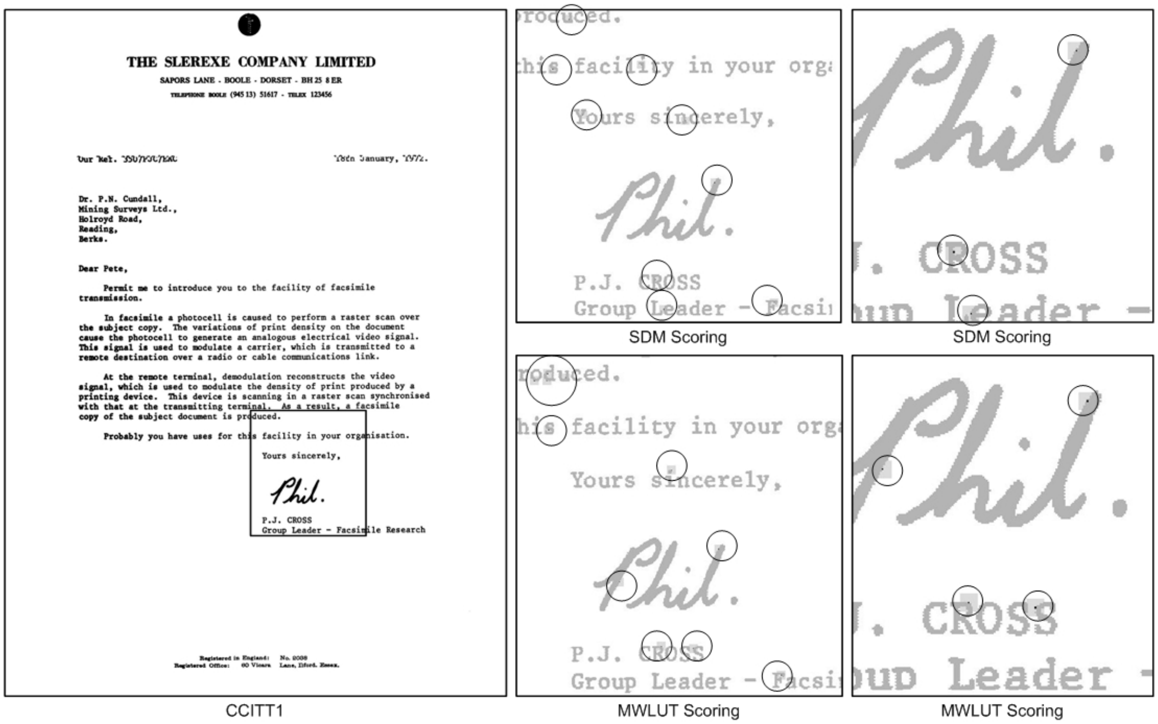

Figure 7. Watermarked versions of an enlarged segment of the CCITT1 image. For presentation purposes only, this binary image was turned into a gray scale image to help spot the modified pixels. The modified pixels are marked black or white dots, and their 5x5 neighborhood is painted with the lighter shade of gray. Those areas are also marked with circles.

Table 3 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 document images CCITT4 and CCITT7 have the same numbers of pixels modified. This means that both pixel scoring methods have identified enough modification candidate pixels to embed the Biz logo message robustly into CCITT4 and 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.

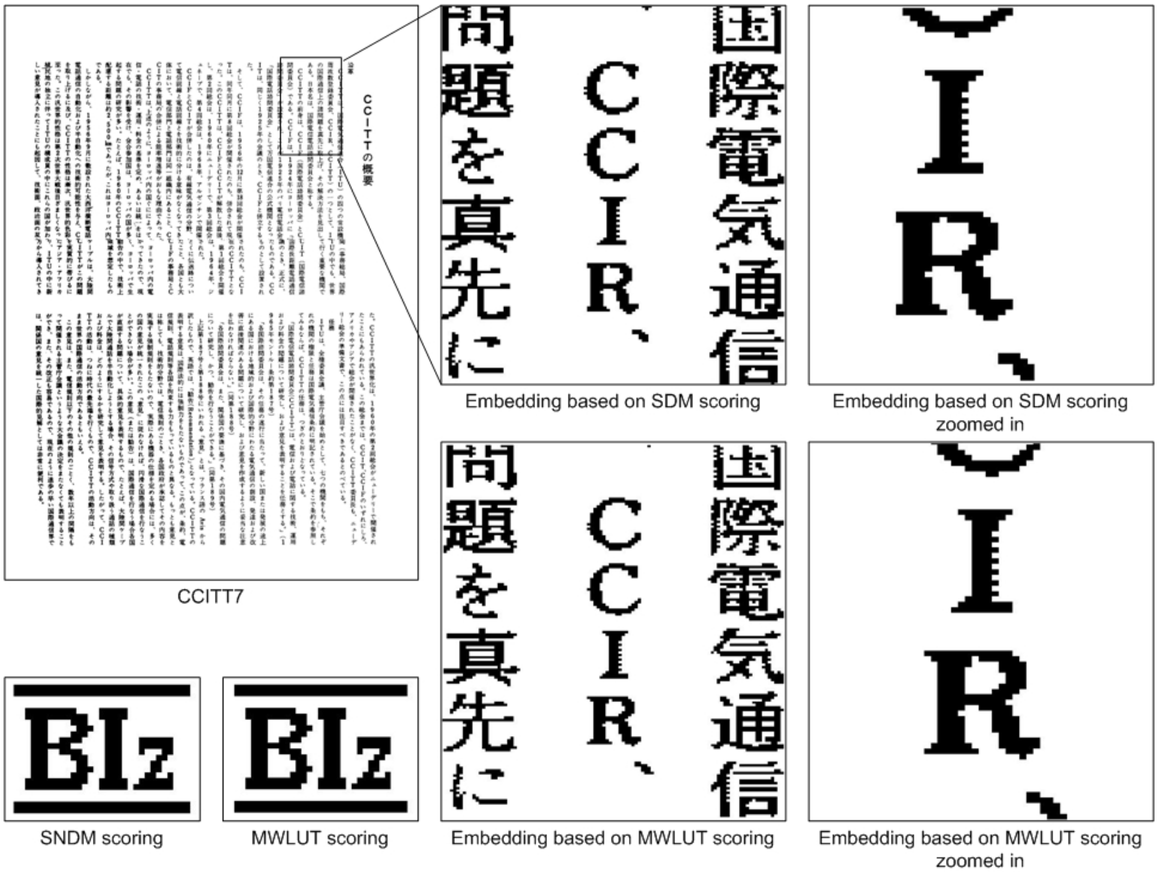

Figure 8 confirms that embedding based on the SNDM pixel scoring results in watermarked images with less visible distortion than embedding based on the MWLUT scores. The Biz logo message is embedded as a robust watermark into the CCITT7 document image using uniform quantization with step size Q=22. Visual inspection of the zoomed in portion of the watermarked document image reveals that various artifacts are more visible when watermark is embedded using pixel candidates selected according to their MWLUT scores. This visual inspection of watermarked images supports DRDM visible distortion results presented in Table 3.

Table 3. Comparison of image distortion results measured using MSE and DRDM between watermark embedding schemes based on MWLUT pixel scoring and SDM pixel scoring. In both cases the 910-bit Biz logo massage was embedded into the set of CCITT images as a robust watermark with Q=22.

	CCITT4	**CCITT7**
MSE (SDM)	4524	4513
MSE (MWLUT)	4524	4513
DRDM (SDM)	0.0023	0.0066
DRDM (MWLUT)	0.0096	0.0206

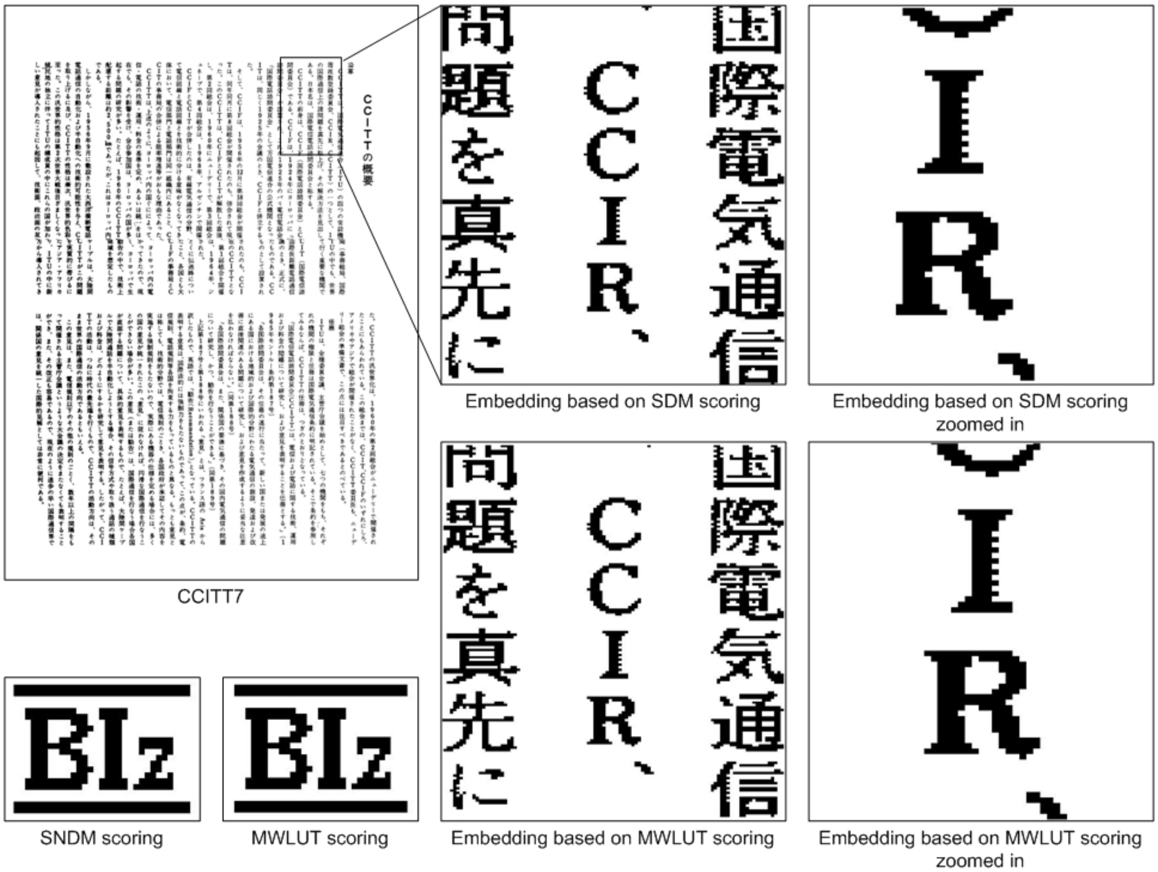

Figure 8. The result of embedding the Biz logo as a robust message using uniform quantization with step size Q=22. Image pixels are modified based on their SDM score in one case and based on the MWLUT in the other case. The DRDM measure suggests that distortion is more visible when embedding is done 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.

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.

Furthermore, the computational complexity of calculating the SDM score is equivalent to the computational complexity of calculating the lookup table access key based on a pixel neighborhood. For example, the SDM score for an image pixel in the 3×3 neighborhood is calculated by convolving the 3×3 image pixels with the 3×3 weight matrix, as follows:

$$SDM_{p_{i,j}} = \sum \left(\begin{bmatrix} p_{i-1,j-1} & p_{i-1,j} & p_{i-1,j+1} \\ p_{i,j-1} & p_{i,j} & p_{i,j+1} \\ p_{i+1,j-1} & p_{i-1,j} & p_{i+1,j+1} \end{bmatrix} \circ \begin{bmatrix} 0.1029 & 0.1471 & 0.1029 \\ 0.1471 & 0 & 0.1471 \\ 0.1029 & 0.1471 & 0.1029 \end{bmatrix} \right), \tag{6}$$

where $p_{i,j}$ is an image pixel an SDM score is calculated for, and $\circ$ is an element-wise matrix multiplication operation. The lookup table access key in the same pixel neighborhood is calculated as follows:

$$LUT\_key_{p_{i,j}} = \sum \left(\begin{bmatrix} p_{i-1,j-1} & p_{i-1,j} & p_{i-1,j+1} \\ p_{i,j-1} & p_{i,j} & p_{i,j+1} \\ p_{i+1,j-1} & p_{i-1,j} & p_{i+1,j+1} \end{bmatrix} \circ \begin{bmatrix} 256 & 32 & 4 \\ 128 & 16 & 2 \\ 64 & 8 & 1 \end{bmatrix} \right), \tag{7}$$

In order to read pixel modification scores from the pre-compiled lookup table, the calculation given in the Equation (7) is performed. It is obvious that the element-wise multiplication of two 3×3 matrices followed by summation of all matrix elements required for calculation of the LUT access key is equivalent to the element-wise multiplication of two matrices followed by summation of all matrix elements performed by Equation (6), which calculates the SDM score. Therefore, the computational complexity of calculation of SDM score is equivalent to the computational complexity of accessing a pre-compiled score from the LUT.

REFERENCES

[1] Chen, M., Wong, E.K., Memon, N. and Adams, S. "Recent developments in document image watermarking and data hiding,“ *in Proc. SPIE Conf. 4518: Multimedia Systems and Applications IV*, (August 2001): 166-176.

[2] Chen, B., and Wornell, G.W. "Quantization index modulation: a class of provably good methods for digital watermarking and information embedding," *IEEE Transactions on Information Theory*, vol. 47(4), (May 2001): 1423 -1443.

[3] Franti, P. and Ageenko, E.I. "On the use of context tree for binary image compression," *in Proc. ICIP*, (October 1999): 752-756.

[4] Furht, B., Muharemagic, E., and Socek, D. "Multimedia Security: Encryption and Watermarking", Kluwer Academic Publishers, 2005

[5] Koch, E. and Zhao, J. "Embedding robust labels into images for copyright protection", *in Proc. Intl. Congress on Intellectual Property Rights for Specialized Information, Knowledge & New Technologies, Vienna*, (Aug. 1995).

[6] Lu, H. Wang, J. Kot, A.C. and Shi, Y.Q "An objective distortion measure for binary document images based on human visual perception,“ *in Proc. Int. Conf. on Pattern Recognition,* vol. 4, (August 2002): 239-242.

[7] Mei, Q. , Wong, E.K., and Memon, N. "Data hiding in binary text documents," *in Proc. SPIE Conf.: Security and Watermarking of Multimedia Contents III,* (January 2001): 166-176.

[8] Muharemagic, E., and Furht, B. "Survey of Watermarking Techniques and Applications", in Multimedia Security Handbook, CRC Press, (2004).

[9] Wu M., and Liu, B. "Data hiding in image and video: Part I – Fundamental Issues and Solutions," *IEEE Transactions on Image Processing*, vol. 12, no. 6, (June 2003).

[10] Wu, M., Yu H., and Liu, B. "Data hiding in image and video: Part II – Designs and Applications," *IEEE Transactions on Image Processing*, vol. 12, no 6, (June 2003).

[11] Wu, M., Tang, E., and Liu, B. "Data hiding in digital binary images," *in Proc. IEEE Int'l Conf. on Multimedia and Expo,* (August 2000).