INVISIBLE DIGITAL WATERMARKING IN THE SPATIAL AND DCT DOMAINS FOR COLOR IMAGES

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Abstract – This paper presents two digital watermarking schemes for embedding a grayscale watermark into color images. The first embeds the watermark directly into the spatial domain while the other embeds the watermark after converting to the DCT Domain. In both schemes, following the pixel modification, the watermark is redirected into the saturation component of the image. The original image is needed in the extraction process. The result of both schemes produces a watermarked image that is no different visibly from the original image.

Index Terms – Digital watermark, discrete cosine transform, pseudorandom permutation, spatial domain.

I. INTRODUCTION

With the continued rise of sharing over the Internet, it is getting increasingly more difficult to prevent copyright infringement of digital media. This paper deals only with ownership of digital images, but the problem is prevalent in all types of digital media, including videos and sound files. The increasing difficulty in protecting copyright ownership makes research in this field ever more important.

There are many different types of digital watermarking, with different goals, and many schemes to accomplish those types of watermarking. Digital watermarking is the process of embedding information into an image that can identify where the image came from or who has rights to it. In some watermarking schemes, a watermarked image has a logo or some other information embedded into the image so that it is readily visible, however these watermarks can be easily corrupted or removed using simple image processing techniques. Most watermarking schemes use invisible watermarking, in which the information is virtually invisible after it is embedded.

Watermark embedding can be achieved in a number of different ways. Some techniques embed a binary pattern into the spatial domain of an image. Usually, the information can be embedded while taking into account which areas of the original image can hold more information while remaining undetectable [1]-[6]. The watermark is embedded by directly modifying pixel values in the spatial domain. However, other watermarking schemes are achieved by embedding the information in the transform domain of an image, either the Discrete Wavelet Transform (DWT) domain or the Discrete Cosine Transform (DCT) domain [1],[7]-[10]. These schemes usually convert the image into one of the transform domains and then embed the watermark information by adjusting the transform domain coefficients. The image is then transformed back into the spatial domain. Most watermarking schemes focus on watermarking black and white or grayscale images. This paper focuses on embedding watermarks into color images, as do [11] and [12]. [11] embeds the watermark in the DCT domain, as do two of the methods described in this paper. Watermarking color images adds another dimension to the process because the image has an extra dimension originally.

This paper describes two watermarking schemes in an attempt to improve watermark robustness to attacks. The first scheme embeds a pseudorandomly permuted grayscale watermark into a color image by adding one watermark pixel to every pixel in each 8x8 pixel block of the achromatic component of the original image. The watermark is then redirected into the saturation component of the image so as to decrease visibility. The second scheme applies a DCT operation to each 8x8 pixel block of the achromatic image and then embeds the watermark in the first 2x2 pixel block in each 8x8 pixel block. The blocks are then converted back to the spatial domain and the watermark is once again redirected into the saturation component. The images are then corrupted using JPEG-lossy compression, rescaling, cropping, and a Gaussian filter, and the watermarks are extracted.

II. WATERMARK EMBEDDING SCHEMES

A. Spatial Domain Watermark Embedding Scheme

Overview:

We will first embed the watermark into X (step 4), and then redirect the watermark to the saturation component of the image (step 5).

Our original image, f is a color image of size MxN and will be represented by :

$$f = \{ f(x,y), 0 \le x < M, 0 \le y < N\}. \quad (1)$$

Our watermark will be a grayscale image of size M/8xN/8. It is represented by:

$$W=\{W(i,j), 0\le i<M/8, 0\le j<N/8\}. \quad (2)$$

Step 1: Find the achromatic component of the host image
Compute the achromatic component of a color image using [X,X,X]^T where X(x,y) = min(R(x,y),G(x,y),B(x,y)).

Step 2: Break the achromatic image into blocks
Break the achromatic component of f, X, into 8x8 pixel blocks. Therefore, X will now be represented as follows:

$$X = \{X_{i,j}(m,n),\ 0\leq i<M/8,\ 0\leq j<N/8,\ 0\leq m,n<8\}. \quad (3)$$

In Step 4, one pixel of the watermark will be embedded into each pixel of the corresponding block.

Step 3: Pseudorandom Permutation of the Watermark
Perform a pseudorandom permutation of the watermark to reduce its vulnerability. Reorder the pixels in the original watermark according to a pseudorandom sequence that can be reproduced in the extraction step. This can be achieved by numbering each pixel in the watermark from 0 to M/8 * N/8 – 1 and then generating the numbers in a random order. The permuted watermark is expressed as follows:

$$W_p = \{W_p(i',j')=W(i,j),\ 0\leq i,i'<M/8,\ 0\leq j,j'<N/8\} \quad (4)$$

where (i',j') are the new coordinates of (i,j) after the permutation.

Step 4: Embed the watermark into the Achromatic Component
Embed the first pixel of the permuted watermark into each pixel in the first block of the achromatic component X until every pixel of the watermark has been embedded in one block of X. The following equation is used to embed the watermark pixels:

$$X'_{i,j}(m,n) = X_{i,j}(m,n)+1/8(\alpha*W_p(i,j)) \quad (5)$$

where $0\leq i<M/8$, $0\leq j<N/8$, $0\leq m,n<8$ and α is an adjustable threshold that represents the embedded strength of the watermark.

Step 5: Redirect the Watermark into the Saturation Component of the Color Image
The purpose of redirecting the watermark to the saturation component is to improve the invisibility of the watermark in the watermarked image. The saturation component is chosen to carry the adjustment because is is less perceptible to the human eye. Also, after adjustment of the saturation component of a color image, the intensity and hue remain unchanged. Therefore, it is possible to change only the saturation component without effecting other aspects of the image. See paper for proof of this property. So, a linear conversion model from RGB color space to the IHS (HSV)color space is used to redirect the watermark. The conversion model is as follows:

$$[I;\ u1;\ u2] = [1/3,\ 1/3,\ 1/3;\ -sqrt(2)/6,\ sqrt(2)/6,\ 2sqrt(2)/6;\ 1/sqrt(2),\ -1/sqrt(2),\ 0] *[R;\ G;\ B] \quad (6)$$

where R,G,and B are the red, green, and blue components,respectively, of the original color image. I is the intensity component and the hue, H, and saturation, S, components can be found from the following equations:

$$H = \tan^{-1}(u2/u1) \quad (7)$$

$$S = sqrt(u1^2 + u2^2). \quad (8)$$

From this linear conversion model we get an equation for redirecting the watermark into the saturation component.

$$[R';\ G';\ B'] = (\ I / (\ I - \beta*X')\ )*[R-\beta*X';\ G-\beta\ ';\ B-\beta*X'] \quad (9)$$

where beta is a scaling parameter, adjusted to achieve watermark invisibility.(beta<1), R',G',B' are the red, green, and blue components, respectively, of the watermarked image. So, [R';G';B'] represents the final watermarked image. The parameters alpha and beta can me manipulated so that there is no visible change between the watermarked image and the original image.

B. Spatial Domain Watermark Extraction Scheme
The type of extraction outlined in this paper is called a non-blind extraction because original image, along with the watermarked image, are needed to extract the watermark.

Step 1: Find Achromatic Component of Original Image

Step 2: Reverse the Saturation Adjustment and Find the Achromatic Component of the Watermarked Image
Estimate the achromatic component of the watermarked image using the following equation:

$$X'' = (\ I\ (\ S''- S\ )\ ) / (\ \beta*S''\ ). \quad (10)$$

The saturation and intensity of the original image, S and I, respectively, along with the saturation of the watermarked image, S'', will be used to reverse the saturation adjustment and find the achromatic component of the watermarked image, represented by X''. This equation is obtained using the relationship between S, the saturation of the original image, and S_{sa}, the saturation after the saturation adjustment, as defined in [1].

Step 3: Break the achromatic components into blocks
Break both achromatic components, X and X'', into 8x8 pixel blocks.

Step 4: Extract the permuted Watermark
Extract the permuted watermark, W''p, from X'' using the following equation:

$$W''_p = \{W''_p(i,j) =(8/\alpha)(1/64)\Sigma_{m=0}^{7}\Sigma_{n=0}^{7}(X''_{i,j}(m,n)-$$

$X_{i,j}(m,n)), 0 \le i < M/8, 0 \le j < N/8\}$. (11)

In other words, a single watermark pixel will be the average of the sum of the differences between each pixel within the corresponding block of X" and X.

Step 5: Reverse Pseudorandom Permutation

Regenerate the random number sequence generated in Step 3 of the embedding process. Use this sequence to put the pixels back in their original order.

C. Cox DCT Domain Watermark Embedding Scheme

Overview:

In this process, first, a DCT transform operation is performed on each 8x8 pixel block of the achromatic component (step 3). Then, the watermark is embedded into 9 of the DCT coefficients (step 5), and after performing the reverse DCT operation to return to the spatial domain (step 6), the watermark is once again redirected to the saturation component of the image (step 5).

Like in the Spatial Domain Watermark Embedding Scheme, the original image, f is a color image of size MxN and will be represented by (1). The watermark will be a grayscale image of size M/8xN/8. It is represented by (2).

Step 1: Find the achromatic component of the host image

Step 2: Break the achromatic image into blocks

Step 3: Convert to DCT Domain

Apply a DCT operation on each block of the achromatic component of the original image. Once in the DCT domain, the first pixel of each block will be the average value of the other blocks and the rest of the coefficients are arranged in a zig-zag scan starting from the pixel directly to the right of the first pixel, which will have the lowest frequency, and ending with the last pixel, which will have the highest frequency.

In the proposed process, the watermark is embedded into the first 2x2 pixel block of each 8x8 pixel block. The reason is as follows: The human eye is more sensitive to lower-frequency components than to higher-frequency components. This means that most of the important information in an image is contained in the lower-frequency components. So, the higher frequency components can be discarded without visible degrading the image. For this reason, the higher-frequency components would not be a good place to embed watermark information. So, by embedding the watermark in the lower-frequency coefficients, the watermark is the safest from corruption.

Step 4: Pseudorandom Permutation of the Watermark

Step 5: Embed the Permuted Watermark

Embed each watermark pixel into the first 2x2 pixel block, in each 8x8 pixel block. The watermark is embedded using the following equation:

$$X'_{i,j}(m,n) = X_{i,j}(m,n)+(\alpha * W(i,j)) \quad (12)$$

where $0 \le i < M/8$, $0 \le j < N/8$, $1 \le m,n \le 2$ and α is an adjustable threshold that represents the embedded strength of the watermark.

Step 6: Convert back to Spatial Domain

To convert back to the spatial domain, an inverse DCT operation is applied to each block in the watermarked achromatic component, X'.

Step 7: Redirect the Watermark into the Saturation Component of the Color Image

D. Cox DCT Domain Extraction Scheme

Again, this extraction scheme is a non-blind extraction scheme and so, both the original image and the watermarked image will be needed to complete the extraction.

Step 1: Find Achromatic Component of Original Image

Step 2: Reverse the Saturation Adjustment and Find the Achromatic Component of the Watermarked Image

Step 3: Break the achromatic components into blocks

Step 4: Converting to the DCT Domain

Apply the DCT operation on each block of the achromatic components of both the original image and the watermarked image.

Step 5: Extract the permuted Watermark

Extract the permuted watermark, W''_p , from X" using the following equation:

$$W''_p = \{W''_p(i,j) = (1/\alpha)(1/4)\Sigma_{m=1}^{2} \Sigma_{n=1}^{2} (X''_{i,j}(m,n)-X_{i,j}(m,n)), \quad 0 \le i < M/8, \quad 0 \le j < N/8\}. \quad (13)$$

In other words, a single extracted watermark pixel will be the average of the sum of the differences between each of the 9 pixels in which the watermark was embedded within the corresponding block of X" and X.

Step 6: Reverse Pseudorandom Permutation

E. Watermark Correlation Coefficient

After a watermark has been extracted, the correlation between the extracted watermark and the original watermark should be calculated. The correlation coefficient is a way of measuring how close the extracted watermark is to the original watermark that was embedded. It is a good way to check the effectiveness of the watermarking scheme. The correlation coefficient is calculated with the following equation:

correlation coefficient (CC) =

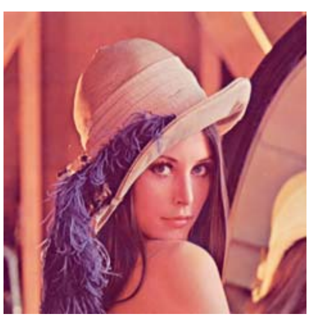
$$\frac{\sum_i \sum_j (W(i,j) - m_W)(W'(i,j) - m_{W'})}{\sqrt{\sum_i \sum_j (W(i,j) - m_W)^2 \cdot \sum_i \sum_j (W'(i,j) - m_{W'})^2}} \quad (14)$$

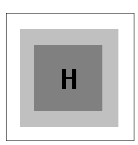
where m_W and $m_{W'}$ are the mean values of the original watermark and extracted watermark, respectively. A correlation coefficient value of 1.0 means the watermark was extracted perfectly.

III. EXPERIMENTAL RESULTS

As shown in Figures 1-3, the proposed methods of watermarking achieved embedding the watermark with no visible change to the original image. Figure 4 is the watermarked image before the saturation adjustment was completed. As you can see, the saturation adjustment is necessary to make the watermark invisible. The extraction methods were able to extract the watermark almost perfectly with no attacks. However, as you can see from Figure 5, the correlation coefficient decreased dramatically as the quality of JPEG-lossy compression decreased, although the Spatial Domain method and DCT Domain method, which are equivalent, faired better than the second DCT Domain method. All three watermarking methods were able to resist an attack with a 3x3 Gaussian Filter fairly well, however the first two were definitely better, as you can see from Figure 6. None of the methods were resistant to cropping or rescaling, although both DCT Domain methods surpassed the Spatial Domain method under these attacks.

Figure 1 Original Image and Watermark





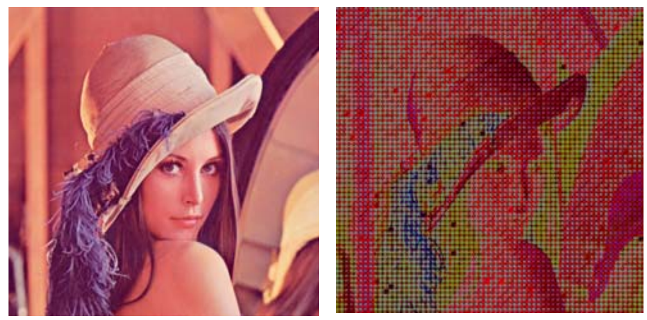
Original Watermark

Figure 2 Watermarked Image using Spatial Domain Method and Difference from Original Image

Figure 5 Correlation Coefficient after JPEG-lossy Compression

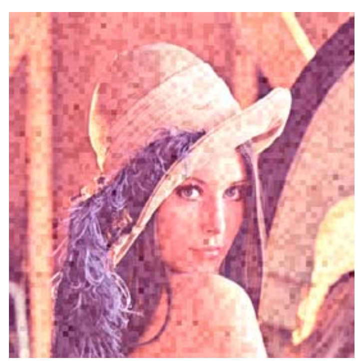
Watermarked Image Difference

Figure 3 Watermarked Image using DCT Domain Method and Difference from Original Image



Watermarked Image Difference

Figure 4 Watermarked Image without Saturation Adjustment



Watermarked Image

JPEG Compression Quality (%)											
Watermark Method	***10***	***20***	***30***	***40***	***50***	***60***	***70***	***80***	***90***	***100***	***BMP***
Spatial Domain	0.054	0.100	0.123	0.195	0.238	0.300	0.334	0.406	0.560	0.722	0.991
DCT Domain (Huang)	0.054	0.100	0.123	0.195	0.238	0.300	0.334	0.407	0.559	0.722	0.991
DCT Domain	0.039	0.044	0.067	0.109	0.115	0.125	0.146	0.216	0.356	0.651	0.994

Figure 6 Correlation Coefficient after Various Attack Operations

Watermark Method	***Gaussian Filter 3x3***	***Crop 25%***	***Rescale x½***	***Rescale x2***
Spatial Domain	0.925	0.019	0.000	0.008
DCT Domain (Huang)	0.920	0.021	0.000	0.013
DCT Domain	0.749	0.021	0.044	0.012

IV. FUTURE WORK

It would be useful to do further research in resistance to geometric attacks such as cropping and rescaling, as the methods presented in this paper lacked that resistance. It is clear from Figure 5 that resistance to JPEG compression decreases rapidly each time the quality decreases. It would also be very useful to conduct further research on JPEG compression to find a technique that could be incorporated into the proposed watermarking schemes to improve that performance.

REFERENCES

[1] P.S. Huang, C.-S. Chiang, C.-P. Chang, and T.-M. Tu, "Robust spatial watermarking technique for colour images via direct saturation adjustment," *IEEE Proc.-Vis. Image Signal Process.,* vol. 152, no. 5, October 2005.

[2] C.-T. Hsu and J.-L. Wu, "Hidden Digital Watermarks in Images," *IEEE Trans. On Image Processing,* vol. 8, no. 1, January 1999.

[3] I.J. Cox, J. Killian, F.T. Leighton, and T. Shamoon, "Secure Spread Spectrum Watermarking for Multimedia," *IEEE Trans. On Image Processing,* vol. 6, no. 12, December 1997.

[4] S.S. Bedi and S. Verma, *A Design of Secure Watermarking Scheme for Images in Spatial Domain.* IEEE 2006.

[5] R. Bangaleea and H.C.S. Rughooputh. *Performance improvement of spread spectrum spatial-domain watermarking scheme through diversity and attack characterization.* IEEE Africon 2002.

[6] S.P. Maity and M.K. Kundu. *Robust and Blind Spatial Watermarking in Digital Image.*

[7] C.-H. Lee and H.-K. Lee, "Geometric attack resistant watermarking in wavelet transform domain," *Optics Express*, vol. 13, no. 4, February 2005.

[8] J.R. Hernandez, M. Amado, and F. Perez-Gonzales, "DCT-Domain Watermarking Techniques for Still Images: Detector Performance Analysis and a New Structure," *IEEE Transactions of Image Processing,* vol. 9, no. 1, January 2000.

[9] Z.H. Wei, P. Qin, and Y.Q. Fu, "Perceptual Digital Watermark of Images using Wavelet Transform," *IEEE Transactions on Consumer Electronics,* vol. 44, no. 4, November 1998.

[10] N. Kaewkamnerd and K.R. Rao, "Wavelet based image adaptive watermarking scheme," *Electronic Letters,* vol. 36, no. 4, February 2000.

[11] Y. Jun, C. Guo-hua, Z. Yi-jia, "A Practical Multipurpose Color Image Watermarking Algorithm for Copyright Protection and Image Authentication," *International Conference on Digital Telecommunications*, 2006.

[12] N. Ahmidi and R. Safabakhsh, "A Novel DCT-based Approach for Secure Color Image Watermarking," *Proceedings of the International Conference on Information Technology: Coding and Computing*, 2004.