Blind Low Frequency Watermarking Method

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Abstract—We present a low frequency watermarking method adaptive to image content. The image content is analyzed and properties of HVS are exploited to generate a visual mask of the same size as the approximation image. Using this mask we embed the watermark in the approximation image without degrading the image quality. Watermark detection is performed without using the original image. Experimental results show that the proposed watermarking method is robust against most common image processing operations, which can be easily implemented and usually do not degrade the image quality.

Keywords—Blind, digital watermarking, low frequency, visual mask.

I. INTRODUCTION

WITH the advancement of multimedia and networking technologies it becomes easy to copy, manipulate and distribute the digital media (e.g. audio, images, video). These create problems for parties who own digital media and want to protect it from illegal multiplication and distribution. Because of that, there is a need for protecting the intellectual property rights. Digital watermarking has been proposed as a solution for the copyright protection. It is a process of embedding hidden copyright information directly into the digital data by making small, unnoticed for human eye, modifications to them.

Many watermarking algorithms have been proposed in recent years. Although several spatial domain algorithms exist, watermarking is mainly performed in transform domain. Many image transforms such as the discrete Fourier transform (DFT), the discrete cosine transform (DCT), and the discrete wavelet transform (DWT) have been considered.

Cox et al. [1] realized that in order to obtain a robust watermark, the watermark should be embedded in the low frequency components of the image. They argue that the most common image processing operations mainly change the high frequency components. Moreover, if low frequency components are changed, the image quality is degraded and the watermark becomes meaningless. If the watermark is embedded arbitrarily in the low frequencies, without adapting to local image characteristics as in [1], the image quality could

be visually degraded. Another drawback of [1] is its complexity, as the global DCT is performed before embedding the watermark. In [2], [3] a block DCT is used, and the watermark is embedded in the middle frequency components of the 8×8 DCT blocks. The low frequency components are left unchanged in order to decrease the visibility of the watermark. However, this results in a decrease in robustness. By switching from DCT to DWT as the image compression method, much more attention is paid to wavelet based watermarking algorithms. In [4] the basic idea of [1] is extended to DWT, and the watermark is embedded in the largest coefficients of the high frequency subbands. The multiresolution nature of wavelet transform is exploited to obtain perceptually invisible watermark. However, embedding the watermark in high frequency subbands makes this technique vulnerable to attacks such as compression and lowpass filtering. Improvements in performance can be obtained by exploiting the characteristics of the human visual system (HVS) in the watermarking process, as proposed in [5], [6]. Using the visual mask in [6], the watermark is embedded in detail subbands at the first level of the decomposition. According to the authors, the choice of these detail subbands offers the best compromise between robustness and invisibility. They compensate for lower robustness of these coefficients by increasing the watermark strength to its maximum, while preserving imperceptibility, using a visual mask. Proposing a similar watermarking algorithm as in [6], with the same visual mask, the authors of [7] showed that for the same image quality (expressed in PSNR) better robustness is achieved if the watermark is embedded in detail subbands at a higher level of decomposition.

In [8], [9] and [10] robustness to attacks that remove high frequency components of the image is achieved by embedding the watermark in the low frequency components. However, in [8] the issue of perceptual masking is not addressed, while in [9] and [10] only homogeneous and non-homogeneous blocks are distinguished. In [10] implicit luminance masking is applied with the embedding formula. However, the original image is needed for detection in this case.

In this paper we present a low frequency image adaptive watermarking method [11]. Robustness to attacks that remove high frequency components of the image is achieved by embedding the watermark in the low frequency components of the original image. The low frequencies components can be obtained using either DWT or block transform (DCT or Generalized Lapped Orthogonal Transform (GenLOT)). Embedding the watermark in the approximation image in an arbitrary manner could destroy the perceptual quality of the image. To embed the watermark with a minimal loss in image

fidelity, watermark strength modulation is performed according to the visual mask that takes into consideration the local image characteristics. The visual mask makes use of HVS properties such as texture, edge presence, and luminance. Detection is performed without use of the original image.

The basic idea for our watermarking method comes from [12] where watermarking in spatial domain is proposed. In [9] the same idea is used for low frequency watermarking. However, although there are more issues that have influence to the HVS, in [9] only texture masking is taken into account. In our watermarking method we introduce more general visual mask in the watermarking process. In this manner, we increase the watermark strength and improve the perceptual quality of the watermarked image.

In the next section the watermarking method is presented. Generation of the visual mask used in our watermarking method is explained in Section III. Section IV contains experimental results and discussion.

II. WATERMARKING METHOD

First, we extract the low frequency components (i.e., the approximation or reference image) from the original $N\times N$ image $\mathbf{x}$ using either a three-level wavelet decomposition or block transform (DCT or GenLOT). For the wavelet transform, the approximation image is the subimage in the upper left corner of the coefficient matrix. For the block transforms the approximation image can be obtain by grouping the DC coefficients from all image blocks. Next, we generate the masking image $\mathbf{K}$ with the same size as the approximation image. The values of $\mathbf{K}$ give a measure of intensity to allowed distortion for each wavelet coefficient in the approximation image, thereby preserving watermark invisibility. The generation of $\mathbf{K}$ is described in next section.

The watermark pattern S is a binary pattern of the same size as the approximation image ($N/8\times N/8$) and is defined by:

$$\mathbf{S} = \{\mathbf{s}[u,v], \ u \in \{0,...,\frac{N}{8}-1\}, v \in \{0,...,\frac{N}{8}-1\}\},$$
$$\mathbf{s}[u,v] \in \{-1,1\} \tag{1}$$

where the values $\mathbf{s}[u,v]$ are generated using the owner key (e.g., the seed of a pseudorandom sequence).
Using S we can split the approximation image LL into two subsets $\mathbf{A}$ and $\mathbf{B}$:

$$\mathbf{A} = \{\mathbf{x}[u,v] \in LL, \ \mathbf{s}[u,v]=1\}$$
$$\mathbf{B} = \{\mathbf{x}[u,v] \in LL, \ \mathbf{s}[u,v]=-1\} \tag{2}$$

In order to improve the performance of the detector for a given seed of the pseudorandom number generator we select sequence $\mathbf{s}[u,v]$ that maximizes the difference of the sample means of the sets $\mathbf{A}$ and $\mathbf{B}$ [9]. In the process of watermark embedding two new subsets $\mathbf{C}$ and $\mathbf{D}$ are created:

$$\mathbf{C} = \{\mathbf{x}[u,v] + \mathbf{k}[u,v], \ \mathbf{x}[u,v] \in \mathbf{A}\}$$
$$\mathbf{D} = \{\mathbf{x}[u,v] - \mathbf{k}[u,v], \ \mathbf{x}[u,v] \in \mathbf{B}\} \tag{3}$$

where $\mathbf{k}[u,v]$ is the $[u,v]$-th coefficient of the masking image $\mathbf{K}$.

Instead of adding a constant K to all coefficients as in [8], or adding one constant for homogeneous and another for non-homogeneous parts of the image as in [9] and [10], we use different constants for all coefficients in the approximation image. In this case K is the mean value of the coefficients in the masking image $\mathbf{K}$. This does not affect the detection algorithm, which does not depend on single bits, but rather on the difference of the mean values of the two subsets $\mathbf{C}$ and $\mathbf{D}$: $\overline{w} = \overline{c} - \overline{d}$. Therefore if we manipulate every pixel in $\mathbf{A}$ and $\mathbf{B}$ in a different way, but preserve the average manipulation in the two subsets K, the watermark can still be detected. The difference $\overline{w}$ is expected to be equal to $2K$ for a watermarked image and equal to zero for an image that is not watermarked or watermarked with the watermark different from the one we are looking for. In other words, $\overline{w}$ is a random variable whose mean is zero for an unwatermarked image and $2K$ for an image that has been watermarked. We use hypothesis testing to decide the existence of the watermark. Two hypotheses are:

H_0: There is no watermark in the image
H_1: There is a watermark in the image

The test statistic q that has been used is given by [9]:

$$q = \frac{\overline{w} - \overline{w}_0}{\sigma} \tag{4}$$

where $\overline{w}_0$ and σ are the mean and the standard deviation of the random variable $\overline{w}$. We estimate $\overline{w}_0$ and σ from a very large number of sample values $\overline{w}$ obtained after generating a very large number of watermarks.

Since the number of samples in the test (number of pixels in LL) is enough large (for example, for image with dimension 512×512 and three levels of decomposition this number is 4096) test statistic q can be well approximated with zero-mean and unit variance normal distribution.

In order to decide whether the image is watermarked or not, the value q is compared with a specific threshold T. If $q > T$ the image is considered watermarked, otherwise we conclude that the image is not watermarked with the specific watermark. The threshold T that results in equal probabilities for errors of type I (accept the existence of a watermark, although there is none) and type II (reject the existence of a watermark, although there is one) is given by:

$$T = 2K / 2\sigma \tag{5}$$

This value of T corresponds to a specific certainty level i.e., a probability of correct watermark detection. From the last equation we can obtain the value of K that lead to specified degree of certainty:

$$K = \sigma T \tag{6}$$

III. VISUAL MASK

We generate the masking image **K** using the following properties of the HVS: (1) The eye is less sensitive to noise in highly textured areas; (2) Modification around edges are very noticeable to the eye; and (3) The eye is less sensitive to noise in areas with high and low brightness.

For texture analysis we use the same transformation as used in the watermark embedding process. When DWT is applied for image decomposition, we exploit the spatial-frequency properties of DWT for texture analysis of the original image. Each coefficient in the approximation image obtained after l levels of decomposition represents a $2^l \times 2^l$ spatial area of the original image. Large coefficients in the detail subbands at various resolutions correspond to textured or edge areas in the original image. We can use these coefficients as a measure for texture activity. Let $\mathbf{X}_{l,f}$ be the subband at resolution level $l=0,1,2$ (0 denotes the first level of decomposition) and with orientation $f \in \{0,1,2,3\}$. The texture mask $\mathbf{T}[u,v]$ is the square sum of all wavelet coefficients that correspond to specific coefficients in the approximation image:

$$\mathbf{T}[u,v] =$$
$$\left(\sum_{f=0}^{2} \sum_{l=0}^{2} \sum_{m=1}^{2^{2-l}} \sum_{n=1}^{2^{2-l}} [\mathbf{X}_{l,f}(2^{2-l} \cdot (u-1)+m, 2^{2-l} \cdot (v-1)+n)]^2 \right)^{\alpha} \quad (7)$$

where α is the parameter that controls the range of the $\mathbf{T}[u,v]$ coefficients.

In case of block transform, in blocks with strong changes between neighbouring pixels, the signal energy is concentrated in AC coefficients. In uniform areas of the image energy is concentrated in DC coefficients. Thus, the energy in AC coefficients can be used as a measure of the image roughness. We use the squared sum of the AC coefficients in each block as measure for a texture mask $\mathbf{T}[u,v]$:

$$\mathbf{T}[u,v] = \left(\sum_{1 < i, j \le 8} \mathbf{X}[i,j]^2 \right)^{\alpha} \quad (8)$$

where α is the parameter that controls the range of the $\mathbf{T}[u,v]$ coefficients.

Large values in $\mathbf{T}[u,v]$ may indicate that the corresponding spatial area is either highly textured or contains outstanding edges. The change in each coefficient of the approximation image will affect a certain number of pixels in the original image, depending on filter length and levels of decomposition. If larger strength of the watermark is allotted to coefficients that correspond to areas in the original image that contain outstanding edges the image quality can be degraded since the HVS is sensitive to distortion around edges. In order to avoid significant distortion of the image fidelity, larger strengths of the watermark should be allotted to coefficients that correspond to highly textured areas than to coefficients that correspond to areas that contain outstanding edges.

To separate texture blocks from edge blocks we generate the edge mask $\mathbf{E}[u,v]$ in the following way:

$$\mathbf{E}[u,v] = number\{\mathbf{e}[i,j] \ne 0, \ [i,j] \in B_{(u,v)}\} \quad (9)$$

where $number\{p\}$ denotes the number of points satisfying the condition specified by p; $\mathbf{e}[i,j]$ is a binary edge mask of the original image; $B_{\{u,v\}}$ represents the a corresponding block in case of block transforms or $2^l \times 2^l$ area in case of DWT.

For the binary edge mask $\mathbf{e}[i,j]$ generation for each pixel in the image $\mathbf{x}$ we find its gradient ∇x. In highly textured block, ∇x would be large at a larger number of locations, while in a block with prominent edge ∇x would have large values at much fewer locations. By comparing the magnitude of ∇x to a suitably selected threshold we determine edge points within the image. In this way binary edge mask is generated. By counting the number of edge points in each $2^l \times 2^l$ spatial area of the image, we generate an edge mask $\mathbf{E}[u,v]$. Larger values in this mask indicate that corresponding block is highly textured while smaller values means that the block contains outstanding edges. The product $\mathbf{T}[u,v] \ \mathbf{E}[u,v]$ of the two masks gives greater significance to highly textured areas of the image.

Finally, we incorporate the luminance masking effect of the HVS in the masking image. The human eye is less sensitive to change in regions with high brightness as well as in very dark regions, compared to mid-grey regions, where the distortion is most noticeable. The luminance mask, which takes into account the local brightness, is generated according the grey level values of the coefficients in the approximation image:

$$\mathbf{L}[u,v] = (128 - \mathbf{X}_{2,3}[u,v])^2 / \beta \quad (10)$$

where β is a predetermined constant and $\mathbf{X}_{2,3}[u,v]$ are the lowest resolution coefficients normalized in the range of 0 to 255.

This yields a visual mask

$$\mathbf{K}[u,v] = r_1 \mathbf{T}[u,v] \ \mathbf{E}[u,v] + r_2 \mathbf{L}[u,v] \quad (11)$$

with the same size as the approximation image. The parameters r_1 and r_2 control the watermarking strength for various types of images.

IV. EXPERIMENTAL RESULTS

We performed many experiments on various standard images in order to evaluate the performance of our watermarking method. In this section, we present some of the most significant results for the original 512×512 Lena image decomposed using Haar filters. In order to achieve a probability of false detection equal to 6.3342×10^{-5} (T = 4) the mean value of the coefficients in the mask is set to $K = 10.8$. This value of K results in a PSNR = 42.65 dB of the watermarked image.
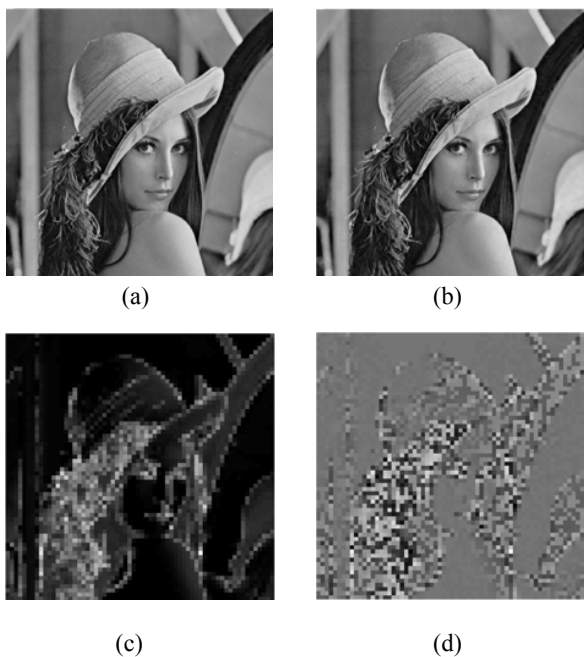
(a)　　　　　　　　(b)

(c)　　　　　　　　(d)

Fig. 1 a) Original 512x512 Lena image b) Watermarked image ($PSNR$ = 42.65 dB) c) Masking image with the same size as approximation image (64x64). Bright areas are less sensitive to noise d) Difference between original and watermarked images

First, we evaluated the perceptual quality of the watermarked image. The original and the watermarked images, together with the generated mask and watermark modulated with this mask are shown in Fig. 1. It can be seen that the original and watermarked images are perceptually undistinguishable, thus validating the invisibility requirement for effective watermarking algorithms. From Fig. 3c and 3d it is evident that a larger strength of the watermark is given to highly textured regions, regions with high brightness, and very dark regions of the image. Mid-gray regions are left almost untouched.

Fig. 2 shows the watermark detector response q to 1000 randomly generated watermarks of which only one (i.e. no. 500) matches the watermark present in Fig. 1a. The response due to correct watermark is much stronger than the response to others, and it is larger than the detection threshold, thus suggesting very low false positive response rates of the algorithm.

Next, we tested the robustness of the watermark to most common image processing operations. In first experiment we examined watermark robustness to JPEG and wavelet based compression. The detector response after JPEG compression for different quality factors is given in Fig. 3. In the same figure the detection threshold and the highest response of the detector produced when 999 incorrect watermarks are tested are also shown. Even when the watermarked image is highly compressed, with a compression ratio of 50, the detector response is above the threshold. The second highest detector response always stays below the threshold, suggesting the low

false negative response rates of the algorithm. The SPIHT algorithm [13] was used for testing the robustness against wavelet-based compression. The watermark presence is detected even at a compression ratio of 80:1.
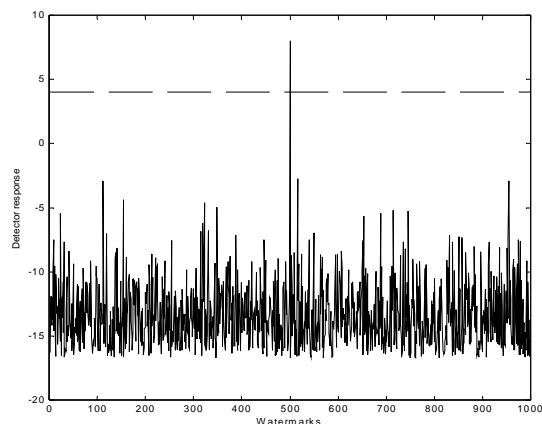

Fig. 2 Detector response on 1000 randomly generated watermarks. Only watermark number 500 is correct
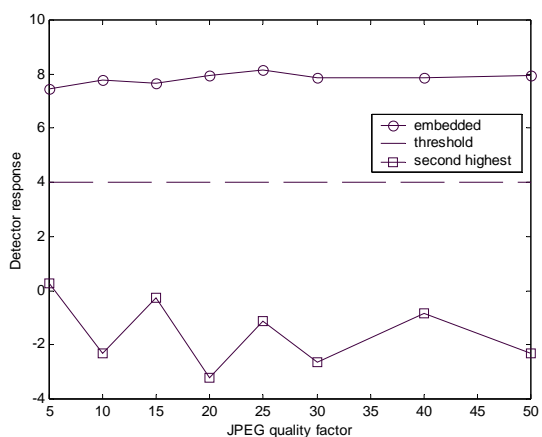

Fig. 3 Detector response to the embedded watermark after JPEG compression

In our second experiment, we investigated robustness to scaling. For this purpose, lowpass filtering followed by downsampling by a factor of 2 was applied to the watermarked image to obtain a 256×256 image. In order to detect the watermark, the scaled image is rescaled back to the size of the original image. The detector response after scaling the watermarked image obtained by the proposed algorithm is 6.12, verifying robustness to this kind of attack.

In Table I we illustrate the robustness of the proposed algorithm to signal processing operations, such as median filtering, additive noise, dithering and sharpening.

V. CONCLUSION

We presented new method for digital watermarking. The watermark is embedded in the low frequency subband of an

TABLE I
DETECTOR RESPONSE AFTER SIGNAL PROCESSING OPERATIONS

Type of attack	Detector response
2x2 median filter	6.11
3x3 median filter	6.29
4x4 median filter	5.52
Additive noise (0, 0.01)	7.79
Dithering	9.90
Sharpening	10.20

image. The low frequency nature of the watermark makes it very robust to common image processing operations. The properties of the human visual system are exploited to generate a visual mask that adaptively determines the optimal strength of the watermark in each low frequency components. As a result, the watermarked images enjoy excellent perceptual quality. Detection is performed without use of the original image. Simulation results support our novel embedding strategy and demonstrate the effectiveness of the proposed approaches both concerning the quality of the marking and its robustness.

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