

Pixel-wise masking for watermarking using local standard deviation and wavelet compression

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Abstract – Perceptual watermarking in the wavelet domain has been proposed for a blind spread spectrum technique, taking into account the noise sensitivity, texture and the luminance content of all the image subbands. In this paper, we propose a modified perceptual mask, where the texture content is appreciated with the aid of the local standard deviation of the original image, which is further compressed in the wavelet domain. The effectiveness of the new perceptual mask is appreciated by comparison with the old watermarking system.

Keywords: image watermarking, discrete wavelet transform, wavelet statistical analysis, perceptual watermark

I. INTRODUCTION

Because of the unrestricted transmission of multimedia data over the Internet, content providers are seeking technologies for protection of copyrighted multimedia content. Watermarking has been proposed as a means of identifying the owner, by secretly embedding an imperceptible signal into the host signal [1]. Important properties of an image watermarking system include perceptual transparency, robustness, security, and data hiding capacity [2].

In this paper, we choose to study a blind watermarking system, which operates in the wavelet domain. The watermark is masked according to the characteristics of the human visual system (HVS), taking into account the texture and the luminance content of all the image subbands. The detection is blind (it does not use the original image). The system that inspired this study is described in [3].

We propose a different perceptual mask based on the local standard deviation of the original image. The local standard deviation is compressed in the wavelet domain to have the same size as the subband where the watermark is to be inserted.

The paper is organized as follows. Section 2 discusses perceptual watermarking; section 3 describes the system proposed in [3]; section 4 presents the new masking technique; some simulation results are

discussed in section 5; finally some conclusions are drawn in section 6.

II. PERCEPTUAL WATERMARKING

One of the qualities required to a watermark is its imperceptibility. There are some ways to assure this quality. One way is to exploit the statistics of the coefficients obtained computing the discrete wavelet transform, DWT, of the host image. We can estimate the coefficients variance at any decomposition level and detect (with the aid of a threshold detector), based on this estimation, the coefficients with large absolute value. Embedding the message in these coefficients, corresponding to the first three wavelet decomposition levels, a robust watermark is obtained. The robustness is proportional with the threshold's value. This solution was proposed by Nafornta, Isar and Borda in [4], where the robustness was also increased by multiple embedding. All the message symbols are embedded using the same strength. The coefficients with large absolute values correspond to pixels localized on the contours of the host image. The coefficients with medium absolute value correspond to pixels localized in the textures and the coefficients with low absolute values correspond to pixels situated in zones with high homogeneity of the host image. The difficulty introduced by the embedding technique already described [4] is to insert the entire message into the contours of the host image, especially when the message is long enough, because only a small number of pixels lie on the contours of the host image. For long messages or for multiple embedding of a short message the threshold value must be decreased and the message is also inserted in the textures of the host image. Hence, the embedding technique already described is perceptual. Unfortunately, the method's robustness analysis is not simple, especially when the number of repetitions is high. The robustness increases due to the increased number of repetitions but it also decreases due to the decreased threshold required (some symbols of the

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message are embedded in regions of the host image with high homogeneity). In fact, there are some coefficients not used for embedding. This is the reason why, some authors like Barni, Bartolini and Piva [3] proposed a different approach for embedding a perceptual watermark in all the coefficients. They prefer to insert the message in *all* detail wavelet coefficients but using *different strengths* (only at the first level of decomposition). For the coefficients corresponding to the contours of the host image they use a higher strength, for the coefficients corresponding to the textures of the host image they use a medium strength and for the coefficients corresponding to the regions with high regularity in the host image they use a lower strength. This is in accordance with the analogy between water-filling and watermarking proposed by Kundur in [5].

III. THE SYSTEM PROPOSED IN [3]

A. Embedding

The image is decomposed into 4 levels using Daubechies-6 wavelet mother, where I_l^θ is the subband from level $l \in \{0,1,2,3\}$, and orientation $\theta \in \{0,1,2,3\}$. A binary watermark $x^\theta(i, j)$ is embedded in all coefficients from the subbands from level 0 by addition:

$$\tilde{I}_0^\theta(i, j) = I_0^\theta(i, j) + \alpha w^\theta(i, j) x^\theta(i, j) \quad (1)$$

where α is the embedding strength and $w^\theta(i, j)$ is a weighing function, which is a half of the quantization step $q_l^\theta(i, j)$.

The quantization step of each coefficient is computed by the authors in [3] as the weighted product of three factors:

$$q_l^\theta(i, j) = \Theta(l, \theta) \Lambda(l, i, j) \Xi(l, i, j)^{0.2} \quad (2)$$

and the embedding takes place only in the first level of decomposition, for $l = 0$.

The first factor is the sensitivity to noise depending on the orientation and on the level of detail:

$$\Theta(l, \theta) = \begin{cases} \sqrt{2}, & \theta = 1 \\ 1 & \text{otherwise} \end{cases} \cdot \begin{cases} 1.00 & l = 0 \\ 0.32 & l = 1 \\ 0.16 & l = 2 \\ 0.10 & l = 3 \end{cases} \quad (3)$$

The second factor takes into account the local brightness based on the gray level values of the low pass version of the image (the 4th level approximation image):

$$\Lambda(l, i, j) = 1 + L'(l, i, j) \quad (4)$$

where

$$L'(l, i, j) = \begin{cases} 1 - L(l, i, j), & L(l, i, j) < 0.5 \\ L(l, i, j), & \text{otherwise} \end{cases} \quad (5)$$

and

$$L(l, i, j) = \frac{1}{256} I_3^3 \left(1 + \left\lfloor \frac{i}{2^{3-l}} \right\rfloor, 1 + \left\lfloor \frac{j}{2^{3-l}} \right\rfloor \right)$$

The third factor is computed as follows:

$$\Xi(l, i, j) = \sum_{k=0}^{3-l} \frac{1}{16^k} \sum_{\theta=0}^2 \sum_{x=0}^1 \sum_{y=0}^1 \left[I_{k+l}^\theta \left(y + \frac{i}{2^k}, x + \frac{j}{2^k} \right) \right]^2 \cdot \text{Var} \left\{ I_3^3 \left(1 + y + \frac{i}{2^{3-l}}, 1 + x + \frac{j}{2^{3-l}} \right) \right\}_{\substack{x=0,1 \\ y=0,1}} \quad (6)$$

and it gives a measure of texture activity in the neighborhood of the pixel. In particular, this term is composed by the product of two contributions; the first is the local mean square value of the DWT coefficients in all detail subbands, while the second is the local variance of the low-pass subband (the 4th level approximation image). Both these contributions are computed in a small 2×2 neighborhood corresponding to the location (i, j) of the pixel. The first contribution can represent the distance from the edges, whereas the second one the texture. This local variance estimation is not so precise, because it is computed with a low resolution. We propose another way of estimating the local standard deviation. In fact, this is our figure of merit.

B. Detection

Detection is made using the correlation between the marked DWT coefficients and the watermarking sequence to be tested for presence:

$$\rho = \frac{1}{3MN} \sum_{\theta=0}^2 \sum_{i=0}^{M-1} \sum_{j=0}^{N-1} \tilde{I}_0^\theta(i, j) x^\theta(i, j) \quad (7)$$

The correlation is compared to a threshold T , computed to grant a given probability of false positive detection, using the Neyman-Pearson criterion. For example, if $P_f \leq 10^{-8}$, the threshold is $T = 3.97 \sqrt{2\sigma_\rho^2}$, with σ_ρ^2 the variance of the wavelet coefficients, if the image was watermarked with a code Y other than X:

$$\sigma_\rho^2 \approx \frac{1}{(3MN)^2} \sum_{\theta=0}^2 \sum_{i=0}^{M-1} \sum_{j=0}^{N-1} (\tilde{I}_0^\theta(i, j))^2 \quad (8)$$

IV. IMPROVED PERCEPTUAL MASK

Another way to generate the third factor of the quantization step is by segmenting the original image, finding its contours, textures and regions with high homogeneity. The criterion used for this segmentation can be the value of the local standard deviation of each pixel of the host image. In a rectangular moving window $N(k, l)$ containing $M \cdot M$ pixels, centered on each pixel $y(k, l)$ of the host image, the local mean is computed with:

$$\hat{\mu}(k, l) = \frac{1}{M \cdot M} \sum_{y(i, j) \in N(k, l)} y(i, j) \quad (9)$$

and the local variance is given by:

$$\hat{\sigma}^2(k, l) = \frac{1}{M \cdot M} \sum_{y(i, j) \in N(k, l)} (y(i, j) - \hat{\mu}(k, l))^2 \quad (10)$$

Its square root represents the local standard deviation. For example, the image Barbara is segmented in classes whose elements have a value of the

normalized local standard deviation, belonging to one of six possible intervals $I_p = (\alpha_p, \alpha_{p+1})$, $p = 1, \dots, 6$, where $\alpha_1=0$, $\alpha_2=0.025$, $\alpha_3=0.05$, $\alpha_4=0.075$, $\alpha_5=0.1$, $\alpha_6=0.25$, $\alpha_7=1$ (Fig.2-7).

This image (Fig.1) was selected for its rich content. It contains a lot of contours, textures and zones with high homogeneity. In each of the Fig. 2-7 is represented the class corresponding to the interval I_p , $p = 1, \dots, 6$, the elements of the other classes being ignored (represented in black). These figures prove the good quality of the segmentation based on the local standard deviation values. Such images can be used like masks for the embedding in the wavelet detail coefficients. The quantization step for a considered coefficient is given by a value proportional with the local standard deviation of the corresponding pixel from the host image.

To assure this perceptual embedding, the dimensions of different detail sub-images must be equal with the dimensions of the corresponding masks. So, the local standard deviation image must be compressed. The compression factor required for the mask corresponding to the l^{th} wavelet decomposition level is 4^{l+1} , with $l=0, \dots, 3$. This compression can be realized with the aid of the DWT. To generate the mask required for the embedding into the detail sub-images corresponding to the l^{th} decomposition level, the DWT of the local standard deviation image is computed (making $l+1$ iterations). The approximation sub-image obtained represents the compression result (the mask required). This type of compression is illustrated in the Fig. 8-11.

The unique difference between the watermarking method proposed in this paper and the one presented in section 3, is given by the computation of the local variance – the second term – in (6). To obtain the new values of the texture, the local variance of the image to be watermarked is computed, using the relations (9) and (10). The local standard deviation image is decomposed using one iteration wavelet transform, and only the approximation image is kept. A scheme is provided in Fig.13. Some practical results of the new watermarking system are reported in the next paragraph.

V. EVALUATION OF THE METHOD

To asses the validity of our algorithm, we give in Fig. 14-17 the results for JPEG compression. The image Barbara is watermarked with various embedding strengths α . The watermarked Barbara for $\alpha=1.5$ is shown in Fig.12. The binary watermark is embedded in all the detail wavelet coefficients of the first resolution level using eq. (1) to (5). Each watermarked image is compressed using the JPEG standard, for six different quality factors: 5, 10, 15, 20, 25, 50.

We choose to show in Fig. 14 & 15 only the ratio ρ/T , as a function of the peak signal-to-noise ratio (PSNR) between the marked (un-attacked) image and the original one, and respectively as a function of α .

For each PSNR and each compression quality factor Q, the correlation ρ and the threshold T are computed. The probability of false positive detection is set to 10^{-8} . The effectiveness of the proposed watermarking system can be measured using the ratio ρ/T . If this ratio is greater than 1 then the watermark can be extracted.

Analyzing Fig. 14, it can be observed that the watermark can be extracted for a large PSNR interval and for a large interval of compression quality factors. For PSNR values higher than 30 dB, the watermarking is invisible. For compression quality factors higher or equal than 25 the distortion introduced by JPEG compression is tolerable. For all values of the PSNR from 30 dB to 35 dB, of practical interest, the watermark can be extracted for all the significant compression quality factors (higher or equal than 25). So, the proposed watermarking method is of high practical interest.

Fig. 15 shows the dependency of the ratio ρ/T on the embedding strength α in case of JPEG compression. Increasing the embedding strength, the PSNR of the watermarked image decreases, and the ratio ρ/T increases.

The ratio ρ/T decreases for higher embedding strengths and for higher compression ratios (Fig.14) or lower embedding strengths (Fig.15). The watermark is still detectable even for very small values of α . For the quality factor Q=5 (or a compression ratio CR=32), the watermark is still detectable even for $\alpha=0.5$.

Fig.16 shows the detection of a true watermark for various quality factors, in the case of $\alpha=1.5$; the threshold is well beyond the detector response.

Finally the selectivity of the watermark detector used is illustrated in Fig. 17, when a number of 1000 different marks were tested. The second highest detector response is shown together with the threshold value, for each quality factor. We can see that false positives are rejected.

In Table 1 we give a comparison between our method and Barni et al method [3]. This time, the algorithm was tested on the Lena image, for $\alpha=1.5$ and a JPEG compression with a quality factor of 5, which yields into a compression ratio of 46. P_f was set to 10^{-8} . We give the detector response for the original embedded watermark ρ , the detection threshold T , and the second highest detector response ρ_2 . P_f was set to 10^{-8} and 1000 marks were tested. The detector response is higher than in the case of the method in [3].

VI. CONCLUSION

We have proposed a new type of pixel-wise masking, based on the local standard deviation of the original image. Wavelet compression was used in order to obtain a texture subimage of the same size with the subimages where the watermark is inserted. We tested the method against compression, and found out that it works better than the method proposed in [3]. Future work will involve testing the new mask on a large

image database and possibly look into using lower resolution levels for embedding, in order to increase robustness.

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Fig.1. Barbara



Fig. 2. The class corresponding to the interval I_6 , contains the contours and the larger textures.



Fig. 3. The class corresponding to the interval I_5 contains contours and textures.



Fig. 4. The class corresponding to the interval I_4 contains textures.



Fig. 5. The class corresponding to the interval I_3 contains textures.



Fig. 6. The class corresponding to the interval I_2 contains textures.



Fig. 7. The class corresponding to the interval I_1 contains the high homogeneity zones.

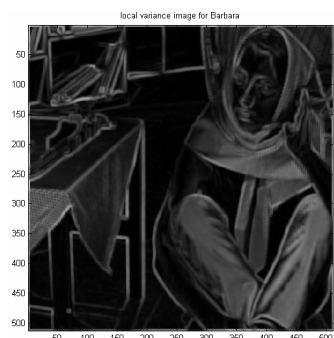


Fig. 8. Local standard deviation of Barbara image.

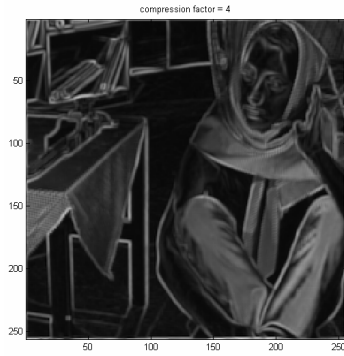


Fig. 9. The last image compressed with CR = 4.



Fig. 11. The image in Fig. 8 compressed with a CR = 64.

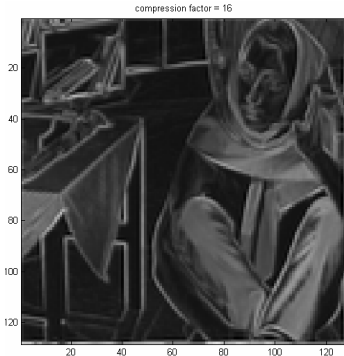


Fig. 10. The image in Fig. 8 compressed with CR = 16.



Fig.12 Watermarked Barbara image with $\alpha = 1.5$.

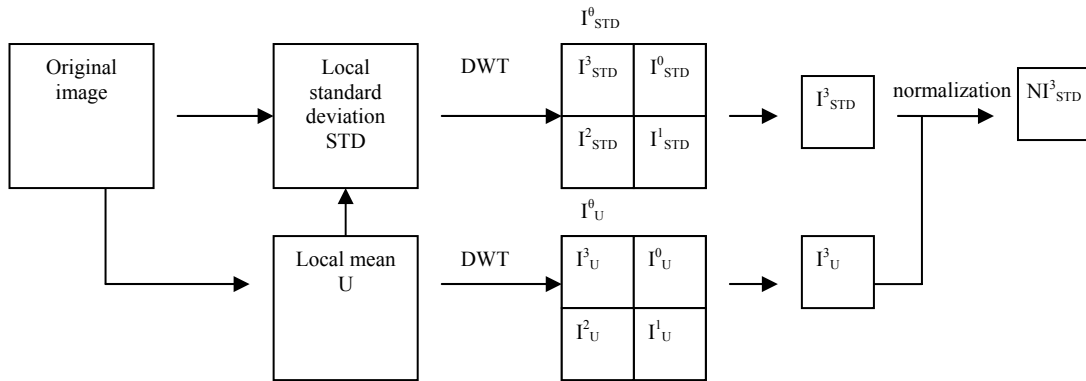


Fig.13: A general scheme for obtaining the texture mask.

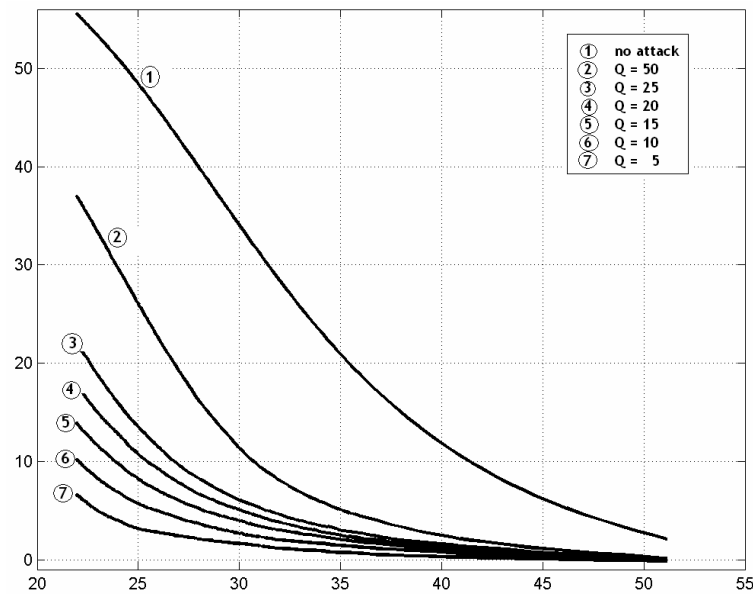


Fig. 14. The ratio ρ/T as a function of the PSNR between the marked and the original images, for different quality factors (JPEG compression). P_f is set to 10^{-8} .

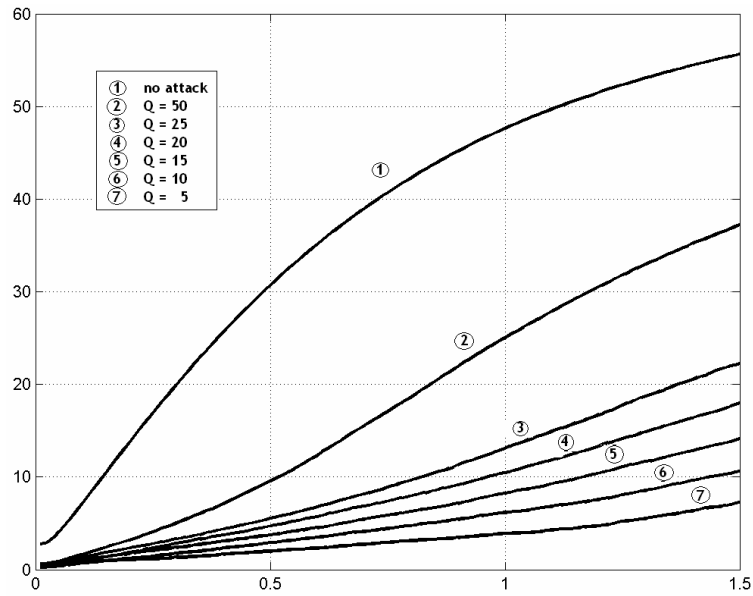


Fig. 15. The ratio ρ/T as a function of the embedding strength, for different quality factors (JPEG compression). P_f is set to 10^{-8} .

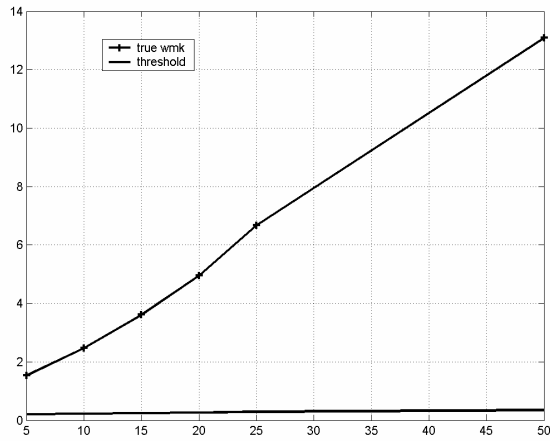


Fig. 16: Detector response ρ , and threshold T , as a function of different quality factors (JPEG compression). The watermark is successfully detected. P_f is set to 10^{-8} .

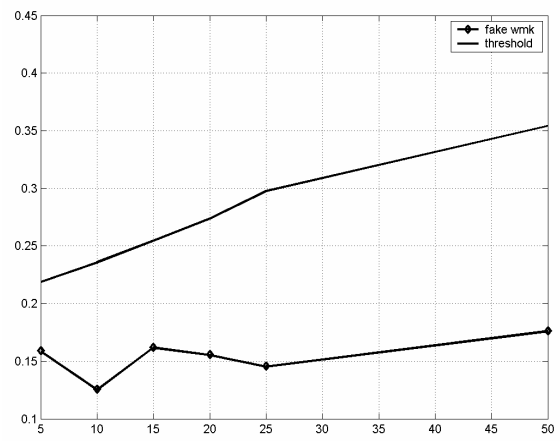


Fig. 17: Highest detector response, ρ_2 , corresponding to a fake watermark and threshold T . The threshold is above the detector response.

Table 1. A comparison between Barni et al method and the proposed one.

CR = 46, JPEG compression	Our method	Barni et al [3] method
ρ	0.3199	0.038
T	0.0844	0.036
ρ_2	0.0516	0.01