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A Robust Wavelet-Based Watermarking Algorithm Using Edge Detection

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***Abstract*—**In this paper, a robust watermarking algorithm using the wavelet transform and edge detection is presented. The efficiency of an image watermarking technique depends on the preservation of visually significant information. This is attained by embedding the watermark transparently with the maximum possible strength. The watermark embedding process is carried over the subband coefficients that lie on edges, where distortions are less noticeable, with a subband level dependent strength. Also, the watermark is embedded to selected coefficients around edges, using a different scale factor for watermark strength, that are captured by a morphological dilation operation. The experimental evaluation of the proposed method shows very good results in terms of robustness and transparency to various attacks such as median filtering, Gaussian noise, JPEG compression and geometrical transformations.

***Keywords*—**Watermarking, wavelet transform, edge detection.

I. Introduction

THE rapid evolution of multimedia systems and the wide distribution of digital data over the World Wide Web addresses the copyright protection of digital information. The aim is to embed copyright information, which is called watermark, on digital data (audio or visual) in order to protect ownership. In general, a digital watermarking technique must satisfy two requirements. First, the watermark should be transparent or perceptually invisible for image data. The second requirement is that the watermark should be resistant to attacks that may remove it or replace it with another watermark. This implies that the watermark should be robust to common signal processing operations, such as compression, filtering, enhancements, rotation, cropping and translation.

The digital image watermarking techniques in the literature are typically grouped in two classes: the spatial domain techniques [1]-[3] which embed the watermark by modifying the pixel values of the original image and the transform domain techniques which embed the watermark in the domain of an invertible transform. The discrete cosine transform (DCT) and the discrete wavelet transform (DWT) are commonly used for watermarking purposes [4]-[12]. The transform domain algorithms modify a subset of the transform coefficients with the watermarking data and generally achieve better robustness than spatial domain methods. Several research works employ the wavelet transform because it presents a number of advantages over the DCT. The wavelet transform is closer to the human visual system (HVS) since it splits the input image into several frequency bands that can be processed independently. It is a multi-resolution transform that permits to locate image features such as smooth areas, edges or textured areas. Some watermarking schemes embed watermarking data in textured areas or edges where the HVS is less sensitive. In some of these schemes, edge tracing is performed employing a unique or several level dependent thresholds [8, 10].

In this paper, an additive watermarking algorithm embeds the signature data to selected groups of wavelet transform coefficients, varying the watermark strength according to the subband level and the group where the corresponding coefficients reside. Initially, the input image is decomposed into four levels by a DWT, resulting in an approximation subband with low frequency components and 12 detail subbands with high frequency components. The proposed algorithm detects edges in each subband using Sobel edge detector and forms two groups of coefficients according to their magnitude. Also, a morphological dilation operation around each edge coefficient captures the coefficients near the edges and forms another group. Finally, the watermark energy is distributed among these groups with a variable strength. The receiver detects the signature data by correlating the watermarked image with the watermark sequence and comparing the correlation factor to a threshold value. The motivation of the present work is to adapt a watermark sequence to the high frequency components of an image, providing a transparent and robust watermark.

II. The Proposed Algorithm

A. The Watermark Embedding Process

Fig. 1 shows the overall process of watermark insertion. The input image is subjected to a four level DWT decomposition using the Daubechies 8-tap filter. The perceptually important wavelet coefficients of each subband are detected by Sobel edge detector and classified into two groups with respect to a threshold value. Also, another group of coefficients is formulated containing the region around the edges. This is accomplished using a morphological dilation operation with a structuring element of 9×9.

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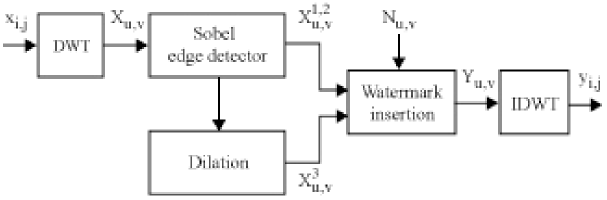
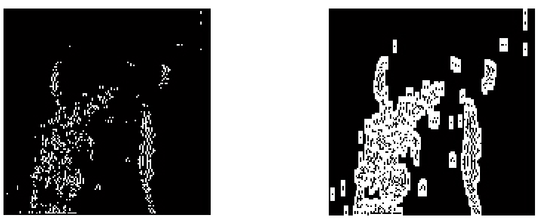


Fig. 1 Block diagram of the watermark insertion process

To the selected coefficients, the watermark is inserted in an additive way using (1). The detail subbands, where the watermark is inserted, contain edge information or high frequency coefficients. Consequently, adding the watermark to these coefficients makes the insertion invisible to the human visual system. Moreover, the insertion is scaled according to the decomposition level and the group that coefficients belong to. Finally, the watermarked image is attained by an inverse transform.

$$Y_{u,v} = (X^{1,2}_{u,v} + X^{3}_{u,v}) + (\alpha^{1,2}_{l} X^{1,2}_{u,v} + \alpha^{3}_{l} X^{3}_{u,v}) N_{u,v} \qquad (1)$$

where $Y_{u,v}$ are the modified wavelet coefficients, $X^{1,2}_{u,v}$ are the edge selected wavelet coefficients classified into two groups, $X^{3}_{u,v}$ are the coefficients around edges captured by dilation, $\alpha^{1,2}_{l}$ and α^{3}_{l} are level dependent parameters controlling the watermark strength for the corresponding groups, and $N_{u,v}$ is the watermark sequence which is represented by Gaussian noise of zero mean and unit variance.



(a) (b)

Fig. 2 Vertical orientation subband at level 2; (a) Edge coefficients; (b) Region around edge coefficients

Fig. 2a illustrates the perceptually significant wavelet coefficients of the vertical detail subband at level 2 for "Lena", whereas Fig. 2b shows the coefficients around the edges. The magnitude of the watermark strength scale factor is selected for each level of the wavelet decomposition such that not severely degrading the watermarked image quality and considering the fact that the average magnitude of the coefficients is approximately doubled in each level from the finest to the coarsest resolution.

B. The Watermark Detection Process

Watermark detection is performed by correlating the marked wavelet coefficients of the possibly attacked watermarked image, $\tilde{y}_{i,j}$, with the watermark to be tested for presence, as Fig. 3 shows.

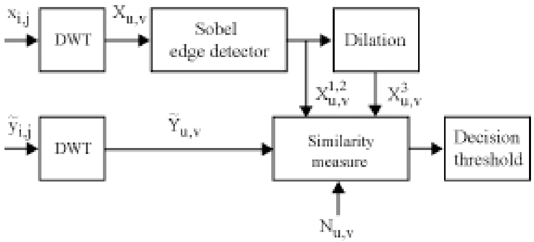


Fig. 3 Block diagram of the watermark detection process

Watermark detection is a non-blind process using (2) [6]:

$$\rho = \frac{1}{MN} \sum_{u=0}^{M-1} \sum_{v=0}^{N-1} \tilde{Y}_{u,v} N_{u,v}, \qquad (2)$$

where $\tilde{Y}_{u,v}$ represents the attacked watermarked coefficients, which provide the groups of the perceptually significant coefficients and $N_{u,v}$ is the watermark sequence.

The correlation factor is compared to a threshold value, as in (3)

$$\begin{array}{ll} \rho > T_w & \textit{true watermark} \\ \rho < T_w & \textit{false watermark}, \end{array} \qquad (3)$$

where

$$T_w = 3.97\sqrt{2\sigma^2}. \qquad (4)$$

Variance σ^2 is defined as

$$\sigma^2 = \frac{1}{(MN)^2} \sum_{u=0}^{M-1} \sum_{v=0}^{N-1} \left(\tilde{Y}_{u,v}\right)^2. \qquad (5)$$

C. Image Quality Assessment

The objective evaluation of image quality is performed by the PSNR, which is defined as

$$PSNR = 10 \log_{10} \left(\frac{255 \times 255}{mse} \right), \qquad (6)$$

where mse is the mean square error:

$$mse = \frac{1}{MN} \sum_{i=0}^{M-1} \sum_{j=0}^{N-1} \left[x(i,j) - y(i,j) \right]^2, \qquad (7)$$

where M, N are the dimensions of the input image and x, y are the original and the watermarked images.

However, PSNR declines from the perceived subjective quality because the HVS does not correlate well with the square of the error. For this reason, the weighted PSNR that takes into account the local variance is also used as follows:

$$wPSNR = 10\log_{10}\left(\frac{255\times 255}{wmse}\right), \qquad (8)$$

where

$$wmse = \frac{1}{MN}\sum_{i=0}^{M-1}\sum_{j=0}^{N-1}\left[\frac{x(i,j)-y(i,j)}{1+\mathrm{var}(i,j)}\right]^2. \qquad (9)$$

III. EXPERIMENTAL RESULTS

The proposed method is evaluated in four images: "Lena", which is an image with large smooth regions, "Barbara", "Baboon" and "Boat", which have textured regions. The size of all images is 512×512 pixels. The performance measures are the invisibility of the inserted watermark and the robustness of the method against various types of attacks. The attacks employed for testing are common signal processing operations such as JPEG compression, median filtering, Gaussian noise and geometrical operations such as cropping and scaling.

Fig. 4 shows the original image of "Lena" and its watermarked copy, whereas Fig. 5 shows their difference. The objective quality of the watermarked copy is about 35 dB with a detector response of about ten times the detection threshold. It is obvious that the watermarked copy is undistinguishable from the original image. In the difference, which is suitably scaled for display, it is evident that watermark data are added to the edges where they are perceptually invisible.

Fig. 4 Original image an its watermarked copy

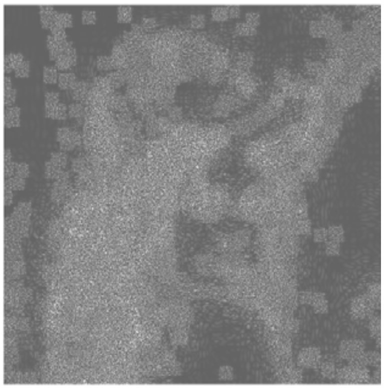


Fig. 5 Scaled difference between original and watermarked images

Table I depicts the objective quality values of the proposed method for the tested images. It is well known that the two desirable features of watermarking, invisibility and robustness, are contradictory. Thus, the values of the watermark strength factor α_l are properly tuned so that the watermarking sequence is completely invisible, with detector response just above the detection threshold (detection strength of about $0.2T_w$).

TABLE I
PSNR & wPSNR VALUES OF WATERMARKED TEST IMAGES

Images	Lena	Barbara	Baboon	Boat
PSNR (dB)	54	51	51	53
wPSNR (dB)	74	71	71	72

It can be seen that, for the same detector response, the watermarked image of "Lena" is of better quality since it has less textured areas than the other images.

Fig. 6 shows the response of the watermark detector to 1000 randomly generated watermarks, with the original watermark placed in the middle. In this case, the watermark strength is such that the watermark sequence is robust enough and the objective quality of the watermarked image is just above 35 dB, which is a typical value just before image is degrading. The robustness of a watermarking algorithm is measured by detection strength, which is the amount that detector's response is higher than the theoretical expected value or detection threshold T_w.

Fig. 7 and Fig. 8 show the detector response of two other typical wavelet-based watermarking algorithms [10, 12] for the same objective image quality.

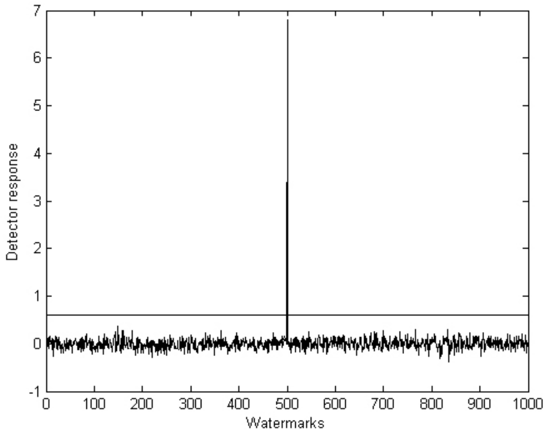


Fig. 6 Response of watermark detector for "Lena"

The first algorithm employs a unique threshold value over all the detail subbands for embedding the signature data, whereas the second algorithm uses the contrast sensitivity function for perceptual tuning of the watermark strength.

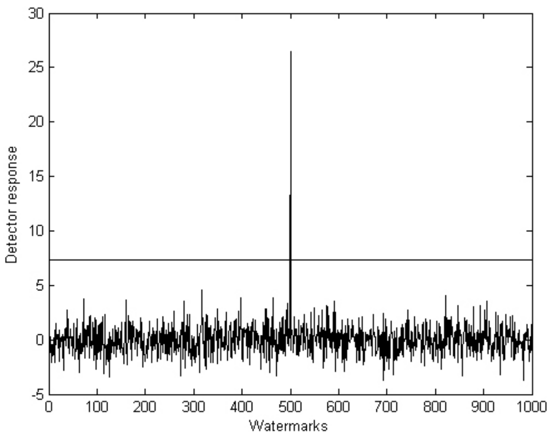


Fig. 7 Dugad et al detector response for "Lena"

It is obvious that the detector response of the proposed algorithm (detection strength of about $10T_w$) is much stronger than the corresponding one of the other methods (detection strength of about $2.5T_w$). This robust performance lies on the fact that watermark data are placed exactly on the detected edges and to a region around them, where HVS is less sensitive to distortions. Moreover, in the proposed method there are no threshold values for tracing edge coefficients, which are image dependent and their tuning to optimum values is a serious drawback.

To appreciate the robustness of the proposed method against several common attacks, the following experiments were performed in "Lena" image.

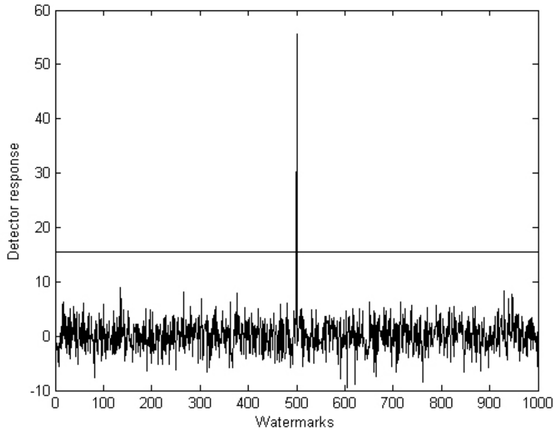


Fig. 8 Ellinas et al detector response for "Lena"

Firstly, JPEG coding with variable quality factor was applied to the watermarked image and 1000 watermarks were inserted for examining the detector's response about their presence. In Fig. 9, the response of the detector to the embedded watermark is plotted against JPEG quality factor. Also, the detection threshold and the second highest response are shown. The detector response remains above threshold up to a quality factor of 5, whereas the second highest response remains always under the threshold value.

Fig. 10 illustrates the detector response after median filtering of the watermarked image with a mask size of 3×3. Comparing this figure with Fig. 6, although watermark is still detectable (detection strength of about $1.5T_w$), we observe that the correlation factor decreases considerably against its initial value because of median filtering. This may be explained since median filtering smoothes the edges of an image where nearly all of the watermarking data have been embedded.

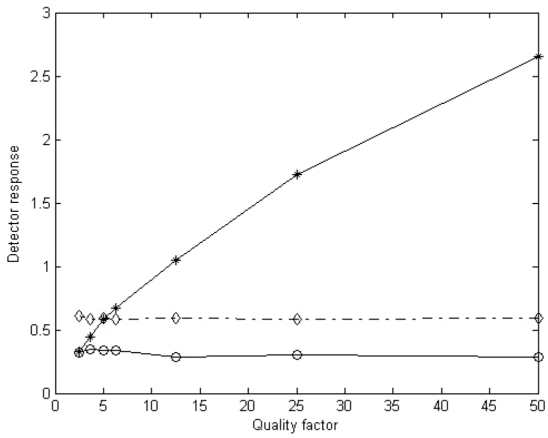


Fig. 9 Detector response versus JPEG quality factor

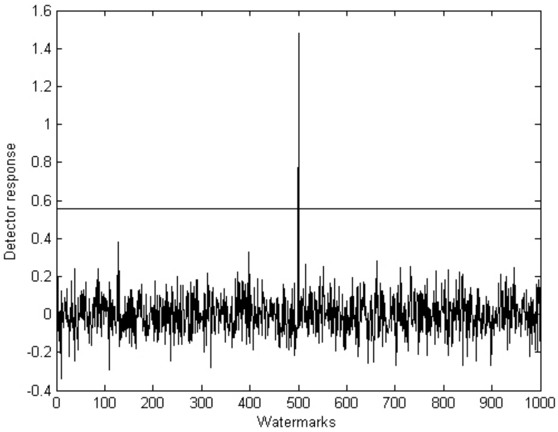


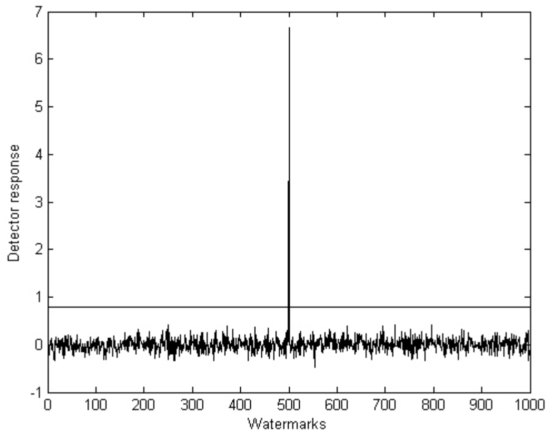
Fig. 10 Detector response after median filtering of the watermarked image

The proposed method is quite immune to Gaussian noise, as Fig. 11 shows. Fig. 11(a) presents the watermarked copy, which has been contaminated with Gaussian noise of zero mean and variance of 30, whereas Fig. 11(b) shows the detector response. The output of the detector is slightly lower than that of Fig. 6, where no attack is involved.

Next, the robustness of the proposed watermarking method against geometrical operations, like cropping and scaling, is examined. When the watermarked image is cropped, part of the embedded information is discarded making the detection more elaborate. Thus, it is important the watermarking method to spread the information all over the image so that, if possible, any remaining part to include enough information for the watermark recovery. Our experiment on cropping is to examine the resilience of the watermark after the removal of a substantial part of the original image. Fig. 12(a) shows the cropped watermarked image which is half of the original image. The ability of the decoder to trace the watermark of the sub-image is shown in Fig. 12(b) (detection strength of about $5T_w$). It is quite impressive that the detector response is well above threshold, revealing the robustness of the proposed method. The watermark sequence is hidden on the wavelet coefficients that reside on the detail subbands or on the edges which exist all over the input image. The proposed method may be less effective when the remaining part contains mainly smooth areas where the embedded information is less, but this is difficult to be accomplished.

Finally, the proposed watermarking method is tested against scaling. The watermarked image is scaled to ¼ of its size by down-sampling. At the detector, the original size is recovered by over-sampling, neglecting the problem of synchronization. Fig. 13 shows the detector response (detection strength of about $1.5T_w$), which is well above the detection threshold.

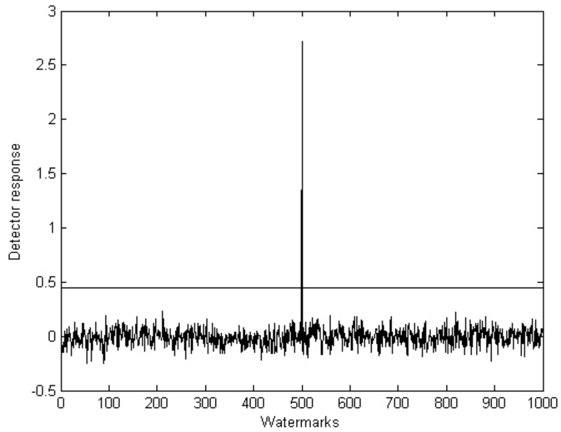
(a)



(b)

Fig. 11 (a) Watermarked copy after Gaussian noise; (b) Detector response of the attacked watermarked image

(a)



(b)

Fig. 12 (a) Cropped watermarked copy (b) Detector response of the cropped watermarked image

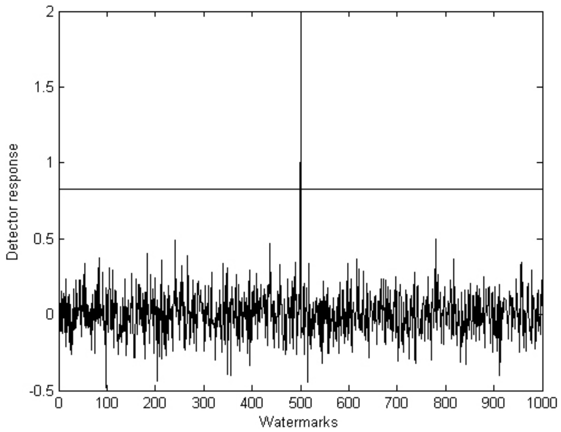


Fig. 13 Detector response of the scaled watermarked image

IV. Conclusion

In this paper, a novel method for image watermarking has been presented. The method embeds the watermarking data on selected groups of wavelet coefficients of the input image. Two groups of coefficients are formed after detecting the edges using a Sobel edge detector and a threshold value. Another group is formulated by a morphological dilation operation applied on the edge coefficients. The selected coefficients reside on the detail subbands and describe the edges of the image or the region around them. The watermark strength is tuned according to the subband level and the group that each coefficient resides in. Thus, exploiting the HVS, which is less sensitive to alterations on high frequencies, the embedded information becomes invisible. The evaluation of the proposed method shows very good performance as far as invisibility and robustness is concerned. The proposed scheme behaves very well in various common signal processing operations as compression, filtering, noise, scaling and cropping.

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References

[1] R. Schyndel, A. Tirkel, and C. Osborne, “A digital watermark,” in *IEEE Proc. Int. Conf. Image Processing*, 1994, vol. 2, pp. 86–90.

[2] W. Bender, D. Gruhl, N. Morimoto, and A. Lu, “Techniques for data hiding,” *IBM Systems Journal*, vol. 35, no. 3-4, pp. 313-336, 1996.

[3] R. B. Wolfgang and E. J. Delp, “A watermark for digital images,” in *IEEE Proc. Int. Conf. Image Processing*, 1996, vol. 3, pp. 219–222.

[4] M. D. Swanson, B. Zhu, and A. H. Tewfik, “Transparent robust image watermarking,” in *IEEE Proc. Int. Conf. Image Processing*, 1996, vol. 3, pp. 211–214.

[5] I. J. Cox, J. Kilian, T. Leighton, and T. Shamoon, “Secure spread spectrum watermarking for multimedia,” *IEEE Trans. Image Processing*, vol. 6, no. 12, pp. 1673–1687, Dec. 1997.

[6] M. Barni, F. Bartolini,a and A. Piva, “Improved wavelet-based watermarking through pixel-wise masking”, *IEEE Trans. Image Processing*, vol. 10, no. 5, pp. 783–791, 2001.

[7] X. Xia, C. G. Boncelet, and G. R. Arce, “A multiresolution watermark for digital images,” in *IEEE Proc. Int. Conf. Image Processing*, USA, 1997, pp. 548-551.

[8] J. R. Kim, and Y. S. Moon, “A robust wavelet-based digital watermarking using level-adaptive thresholding,” in *IEEE Proc. Int. Conf. Image Processing*, Japan, 1999, pp. 226-230.

[9] C. T. Hsu, and J. L. Wu, “Hidden digital watermarks in images,” *IEEE Trans. Image Processing*, vol. 8, no. 1, pp. 58–68, Jan. 1999.

[10] R. Dugad, K. Ratakonda, and N. Ahuja, “A new wavelet-based scheme for watermarking images,” in *IEEE Proc. Int. Conf. Image Processing*, USA, 1998, pp. 419-423.

[11] R. B. Wolfgang, C. I. Podilchuk, and E. J. Delp, “Perceptual watermarks for digital images and video,” in *SPIE Proc. Int. Conf. Security and watermarking of multimedia contents*, USA, 1999, pp. 40-51.

[12] J. N. Ellinas, D. E. Manolakis, “A robust watermarking scheme based on edge detection and contrast sensitivity function,” in *VISAPP Proc. Int. Conf. Computer Vision Theory and Applications*, Barcelona, 2007.

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