A Blind Object Watermarking Scheme Based on SA-DWT*

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Abstract

In this paper, we propose an approach to blind watermarking of objects of images and video based on shape adaptive discrete wavelet transform (SA-DWT). Unlike most watermarking methods, the watermark is not embedded by modulating individual wavelet coefficient but by modulating the weighting mean of coefficients in the wavelet blocks. Experimental results demonstrate that the proposed watermarking scheme is perceptual invisible and robust against many attacks such as lossy image/video compression (e.g., JPEG, JPEG2000 and MPEG-4), scaling, adding noise, filtering, D/A and A/D conversion, etc.

1. Introduction

Due to the digital media revolution and the popularity of Internet commence, the intellectual property right protection is becoming an increasing important issue. As a potential and effective way to solve this problem, digital watermarking becomes a very active research area of signal and information processing. Digital watermarking is a technology that embeds invisible information such as ownership and copyright message into multimedia data to protect the intellectual property right of the content owners. Many watermark algorithms have been proposed to address this issue of ownership identification [1]-[3].

With the development of MPEG-4, this standard is very attractive for a large range of applications such as video editing, Internet, video distribution, wireless video communications. MPEG-4 standard enables the production of content, and is able to access and manipulate directly objects within a video sequence. Frame-based approach has been migrating to object-based approach. Therefore, object watermarking schemes are needed in the MPEG-4 environment.

Several object watermarking methods have been proposed [4]-[6]. Wu et al. [4] propose a multi-resolution object watermarking approach based on the 2D and 3D shape adaptive wavelet transforms. The advantage of the multi-resolution watermarking method is its robust against image/video compression and computational saving. However, the main disadvantage is that original image/video object is required for watermark detection. Kim et al. [5] propose an object-based video watermarking method using the shape adaptive discrete cosine transforms (SA-DCT). The SA-DCT method is superior to all other padding methods in terms of the robustness against the image deformations. But the watermark can be damaged by a wavelet-based image codec in the quantization stage. Therefore, this method limits their applications in the context of JPEG2000 and MPEG-4 due to the fact that the wavelet transform is playing an important role in JPEG2000 and MPEG-4. Piva et al. [6] propose an object watermarking system for MPEG-4 streams. Since this method applies the discrete wavelet transform (DWT) to the whole image and the watermark is embedded in the all wavelet coefficients belonging to the three detail bands at level 0, this may lead to loss of the watermark which is embedded in the region outside the object.

In this paper, we propose an approach to blind watermarking of objects of images and video based on shape adaptive discrete wavelet transform (SA-DWT) [7]. Unlike most watermarking methods, the watermark is not embedded by modulating individual wavelet coefficient but by modulating the weighting mean of coefficients in the wavelet blocks. The human visual system (HVS) is employed to achieve the best tradeoff between perceptual invisibility and robustness to signal processing. Watermark detection is accomplished without the original, unwatermarked object by using statistical detection technique. Experimental results demonstrate that the proposed watermarking scheme is perceptual invisible and robust against unintentional and intentional attacks such as lossy image/video compression (e.g., JPEG, JPEG2000 and MPEG-4), scaling, adding noise, filtering, D/A and A/D conversion, etc.

2. Shape Adaptive Discrete Wavelet Transform

Given an arbitrarily shaped object with shape mask information, the SA-DWT transforms the samples in the arbitrarily shaped region into the same number of

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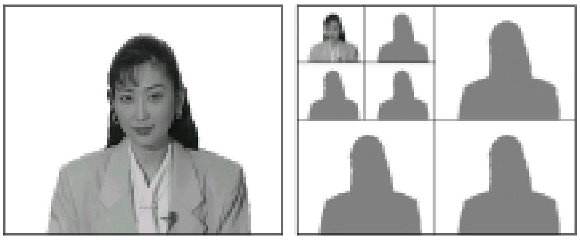
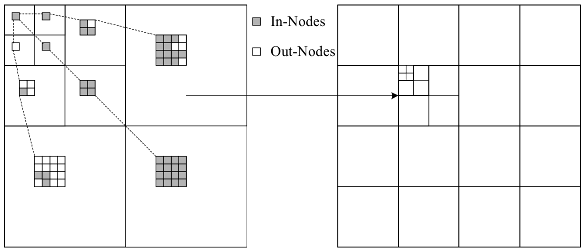


Fig.1. Multi-resolution decomposition of an arbitrarily shaped object



(a) (b)

Fig.2. (a) Parent-child relation of wavelet trees in SA-DWT, (b) Reorganization of a wavelet tree into a wavelet block

coefficients as in the subband domain, while keeping the spatial correlation, locality, and self-similarity across subbands. Fig.1 illustrates the result of a two-level wavelet decomposition of an arbitrarily shaped object. In the SA-DWT decomposition, the shape mask is decomposed into a pyramid of subbands in the same way as the SA-DWT so that each subband has a corresponding shape mask associated with it to specify the locations of the coefficients in that subband. Fig.2 (a) shows the parent-child relation of SA-DWT tree descending from a coefficient in the subband LL3. As shown in the figure, there are two types of nodes in a tree: in-nodes and out-nodes. The major task is to extend the conventional watermarking methods to the case with out-nodes. A simply way is to set all those out-nodes values to zeros and then apply the conventional watermarking methods. However, this may lead to loss of the watermark. To avoid this problem, we reorganized the coefficients of each wavelet tree to form a wavelet block as shown in Fig.2 (b). In this way, the wavelet blocks are classified into two types: *care* blocks that have in-nodes and don't *care* blocks that don't have in-nodes. By doing so, all the don't *care* blocks need not be watermarked and will be skipped, while these out-nodes values in *care* blocks will be set to zeros and later we will adopt a method to ensure that the watermark is not embedded in these out-nodes in *care* blocks.

3. Watermark Embedding

Given a set of wavelet coefficients, it has been observed that the population mean has a smaller variance than that of individual coefficient. Thus, the watermark embedded in the weighting mean of the wavelet blocks is more robust than in the individual coefficient. The basic concept of the weighting mean is similar to that of [8], but is developed independently. The weighting mean of the wavelet block is defined as:

$$\hat{I}(k) = \sum_{i=1}^{N-1} P_i \cdot |I_i(k)| \quad (1)$$

where $I_i(k)$ is the i-th wavelet coefficient in the k-th wavelet block, $i=1\ldots N-1$ and N is the number of coefficients in the wavelet block. $I_0(k)$ denotes the DC coefficient in the k-th wavelet block. P_i is a binary random sequence with uniform distribution, $P_i \in \{-1,1\}$.

If the magnitudes of all $I_i(k)$'s are changed by Ω due to some distortions, then

$$\begin{aligned}\hat{I}'(k) &= \sum_{i=1}^{N-1} P_i \cdot (|I_i(k)| + \Omega) \\ &= \underbrace{\sum_{i=1}^{N-1} P_i \cdot |I_i(k)|}_{\Sigma_1} + \underbrace{\sum_{i=1}^{N-1} P_i \cdot \Omega}_{\Sigma_2}\end{aligned} \quad (2)$$

Since P_i is a binary random sequence with uniform distribution, Σ_2 is approximately zero. Then the weighting mean becomes

$$\hat{I}'(k) = \Sigma_1 + \Sigma_2 \approx \sum_{i=1}^{N-1} P_i \cdot |I_i(k)| = \hat{I}(k) \quad (3)$$

So the weighting mean has the advantage of preserving small variance when some distortions are encountered.

The watermark W, consisting of a binary pseudo random sequence, $W(k) \in \{-1,1\}$, is embedded by modifying the weighting mean of wavelet blocks in this way:

$$\hat{I}'(k) = \hat{I}(k) + \alpha \cdot T(k) \cdot W(k) \quad (4)$$

where $\hat{I}(k)$ is the weighting mean of the k-th wavelet block. α is a scaling factor. To adapt the watermark sequence to the local properties of the wavelet block, we use the quantisation model based on the human visual system [9] in the watermark system. The visual model takes into account the *brightness* sensitivity and *texture* sensitivity of the wavelet block to noise. The weighting function $T(k)$ is defined as:

$$T(k) = brightness(k) \cdot texture(k)^{\beta}$$
$$where, \begin{cases} brightness(k) = 3 + \dfrac{1}{256} I_0(k) \\ texture(k) = Var\{I_i(k) : i = 1\ldots N-1\} \end{cases} \quad (5)$$

and β is set to 0.318 to control the degree of *texture* sensitivity. The eye is less sensitive to noise in the highly bright and the highly textured areas of the image. The function *brightness*(k) estimates the local brightness based on the graylevel values of the low pass subband of the wavelet block and the function *texture*(k) is defined as the local variance of the wavelet block, except for the DC coefficient.

To update the weighting mean $\hat{I}(k)$, each individual coefficient $I_i(k)$ in the k-th wavelet block must be updated accordingly. Let $\Delta = \alpha \cdot T(k) \cdot W(k)$, the following rule can be applied to update $I_i(k)$:

$$I'_i(k) = I_i(k) + P_i \cdot sign(I_i(k)) \cdot \Delta_i$$

$$where, \begin{cases} sign(x) = \begin{cases} +1, & if \quad x > 0 \\ -1, & if \quad x < 0 \end{cases} \\ \Delta_i = \dfrac{|I_i(k)|}{\sum_{i=1}^{N-1} |I_i(k)|} \cdot \Delta \end{cases} \tag{6}$$

If the sign of $I_i(k)$ is changed after applying Eq.(6), then $I'_i(k)$ is set to zero. Δ_i is the magnitude of update on $I_i(k)$. If $I_i(k)$ is the out-node in the *care* wavelet block, then Δ_i=0 due to the fact that the out-nodes values in *care* blocks have been set to zeros. So the watermark will not be embedded in these out-nodes in *care* blocks.

The proof of the rule is presented as follows:
Proof. Let $\Delta = \alpha \cdot T(k) \cdot W(k)$. From Eq.(4), it's obtained: $\hat{I}'(k) = \hat{I}(k) + \Delta$.

Assume $\Delta_i = \dfrac{|I_i(k)|}{\sum_{j=1}^{N-1} |I_j(k)|} \cdot \Delta$, then

$$\begin{aligned} \hat{I}'(k) &= \sum_{i=1}^{N-1} P_i \cdot |I_i(k)| + \sum_{i=1}^{N-1} \Delta_i \\ &= \sum_{i=1}^{N-1} P_i \cdot \left(|I_i(k)| + P_i \cdot \Delta_i\right) \\ &= \sum_{i=1}^{N-1} P_i \cdot sign(I_i(k)) \cdot \left(I_i(k) + P_i \cdot sign(I_i(k)) \cdot \Delta_i\right) \end{aligned}$$

Let $I'_i(k) = I_i(k) + p_i \cdot sign(I_i(k)) \cdot \Delta_i$, and introduce the restraining condition:

if $sign(I'_i(k)) \neq sign(I_i(k))$, then $I'_i(k)$=0.

Therefore, it's obtained

$$\begin{aligned} \hat{I}'(k) &= \sum_{i=1}^{N-1} P_i \cdot sign(I'_i(k)) \cdot I'_i(k) \\ &= \sum_{i=1}^{N-1} P_i \cdot |I'_i(k)| \end{aligned}$$

Thus, when $I_i(k)$ is updated to $I'_i(k)$, the weighting mean $\hat{I}(k)$ is also updated to $\hat{I}'(k)$.

4. Watermark Detection

Watermark detection is accomplished without the original object by correlating the possibly watermarked weighting mean of the wavelet blocks $\hat{I}'$ and the watermark W as follows:

$$c = \frac{\sum_{k=0}^{M-1} Y(k)}{\sigma \cdot \sqrt{M}} = \frac{\mu \cdot \sqrt{M}}{\sigma} \tag{7}$$

where $Y(k) = \hat{I}'(k) \cdot W(k)$, M is the length of the watermark sequence, μ and σ^2 are the mean and the variance of $Y(k)$, given, respectively, by

$$\mu = \frac{\sum_{k=0}^{M-1} Y(k)}{M}; \quad \sigma^2 = \frac{\sum_{k=0}^{M-1} (Y(k) - \mu)^2}{M - 1} \tag{8}$$

If the object is watermarked with W', $W \neq W'$, then the correlation c is given by:

$$c = \frac{\sum_{k=0}^{M-1} \hat{I}(k) \cdot W(k) + \sum_{k=0}^{M-1} \alpha \cdot T(k) \cdot W'(k) \cdot W(k)}{\sigma \cdot \sqrt{M}} \tag{9}$$

If the object is watermarked with W, the correlation c is:

$$c = \frac{\sum_{k=0}^{M-1} \hat{I}(k) \cdot W(k) + \sum_{k=0}^{M-1} \alpha \cdot T(k) \cdot W^2(k)}{\sigma \cdot \sqrt{M}} \tag{10}$$

Assume that $\hat{I}, W$, are independent and identically distributed random variables and W has zero mean value. Under these assumptions, the mean value of c is

$$\mu_c = \begin{cases} 0, & if \quad W \neq W' \quad or \quad No \quad watermark \\ \dfrac{E(\alpha \cdot T(k)) \cdot \sqrt{M}}{\sigma} \cong \dfrac{\alpha \cdot \sum_{k=0}^{M-1} T(k)}{\sigma \cdot \sqrt{M}}, & if \quad W = W' \end{cases} \tag{11}$$

The value of the correlation sum c is then compared with a threshold T_c. The watermark W is considered to be present if $c > T_c$ and absent if $c < T_c$. The threshold T_c that minimizes the total detection errors is $T_c = \mu_c/2$. In our experiments, the threshold T_c=4.

5. Experimental Results

We test our scheme on a number of images and video, but only report results for 'Akiyo' and 'Bream'. In our experiments, we fix α as a constant and choose α=2.0. In order to test the performance of the proposed watermarking scheme, 200 watermarks are randomly generated.

For image objects, we use the foreground objects of the

(a) (b)

Fig.3. (a) Original object 'Akiyo', (b) Watermarked object 'Akiyo' (PSNR=43.52dB).

Fig.4. Absolute difference between the original object 'Akiyo' and the watermarked one, magnified by a factor 32.

first frames (704x480) of 'Akiyo' sequence and 'Bream' sequence. The PSNR results between the original objects and the watermarked objects are 43.52dB(Akiyo) and 41.21dB(Bream). As shown in Fig.3, the watermark is perceptual invisible and the object 'Akiyo' with watermark appear visually identical to the one without watermark. In Fig.4 the absolute difference between the original object 'Akiyo' and the watermarked one, magnified by a factor 32, is shown: it is evident that the watermark is mainly hidden into the regions of high texture and the edges and there is no watermark embedded in the region outside the object. Fig.5 shows the responses of the watermark detector to 200 randomly generated watermarks. The responses to the correct watermark (i.e. number 100) are much higher than the responses to incorrect watermarks.

To evaluate the robustness of our scheme against unintentional and intentional attacks, we test the watermarked objects with JPEG, JPEG2000, scaling, adding noise, filtering, A/D and D/A conversion, etc. We use the LuraWave SmartCompress[10] for JPEG2000 compression, and use Stirmark [11][12] for JPEG compression, scaling and filtering, etc. The watermark detector responses are shown in Table I. These responses are above the threshold T_c (T_c=4) and indicate that the watermark is present.

Table 1. Watermark detector responses after attacks

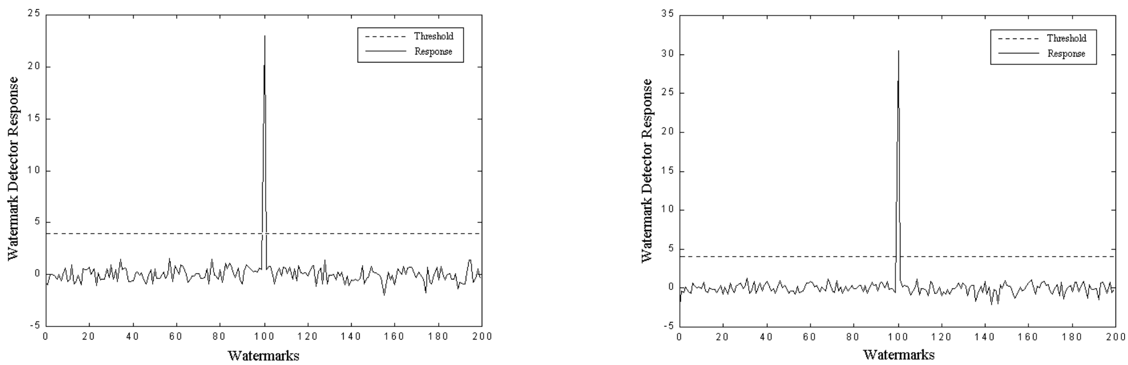
Detector Responses	Akiyo	Bream	Detector Responses	Akiyo	Bream
JPEG quatity 10	5.31	5.82	Uniform noise 10%	11.69	24.15
JPEG quatity 30	8.78	15.12	Uniform noise 20%	8.93	18.81
JPEG quatity 60	11.35	20.97	Uniform noise 30%	5.41	15.13
JPEG2000 quatity 65	7.32	5.74	Gaussian noise 10%	9.39	20.92
JPEG2000 quatity 75	9.20	17.11	Gaussian noise 20%	5.50	13.01
JPEG2000 quatity 85	13.09	22.36	Blur filtering 3x3	9.02	13.35
Scaling 0.5x0.5	8.67	11.68	Median filtering 3x3	9.24	9.92
Scaling 0.5x0.6	9.25	13.61	Gaussian filtering	9.59	15.90
Scaling 2.0x3.0	14.11	23.76	D/A and A/D	10.01	14.21

For video objects, we test our proposed watermarking scheme against MPEG-4 compression. Video sequences used for this experiment are 30 frames (704x480) of 'Akiyo' sequence and 'Bream' sequence.

The watermarks are embedded in video objects before compression, i.e. frame by frame. After watermarking, the sequences are compressed obtaining MPEG-4 coded video bit-stream using MPEG-4 VM Version 12.1 [13], with a rate of 500kbits per Video Object Layer (VOL). The video streams are next decompressed, and in each frame the objects are separated obtaining different images, where the watermark detection process is applied. The PSNR results of the first frames of the decoded foreground objects are 31.96dB (Akiyo) and 27.73dB (Bream). The corresponding watermark detector response is 7.97 and 17.92, respectively, as shown in Fig.6. The responses are well above the threshold T_c and indicate that our proposed watermarking scheme is robust to MPEG-4 compression.

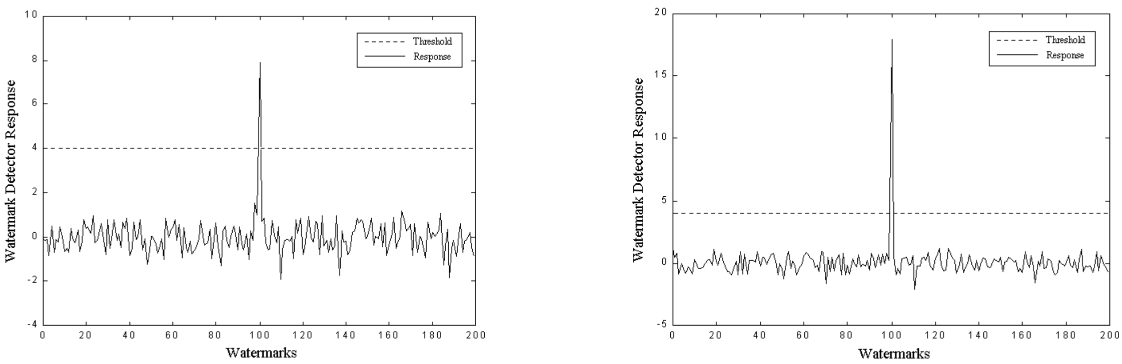
6. Conclusions

In this paper, a novel blind object watermarking scheme for images and video using shape adaptive discrete wavelet transform (SA-DWT) has been proposed. To make the watermark robust and perceptual invisible, we embed it in the weighting mean of the wavelet blocks using the quantisation visual model based on the human



(a) (b)

Fig.5. Watermark detector responses relating to the Image Object 'Akiyo' (a) and the Image Object 'Bream' (b) for 200 randomly generated watermark.



(a) (b)

Fig.6. Watermark detection response relating to the Video Object 'Akiyo' (a) and the Video Object 'Bream' (b) after MPEG-4 compression, with a rate of 500kbits per VOL.

visual system. The visual model takes into account the *brightness* sensitivity and *texture* sensitivity. Watermark detection is accomplished without the original, unwatermarked object by using statistical detection technique. Our proposed scheme can be also applied to watermark-based object retrieving and indexing.

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