ROBUST IMAGE WATERMARKING IN THE SUBBAND OR DISCRETE COSINE TRANSFORM DOMAIN

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ABSTRACT

In this paper a method is presented for copyright protection in digital images. Copyright protection is achieved by embedding an invisible signal, known as digital signature or watermark, in the digital image. The method proposed in this paper casts the signature in the frequency domain by slightly modifying the values of randomly selected DC coefficients of the Discrete Cosine Transform (DCT) of the image. The same method is applied also on the Subband or Wavelet Transform coefficients. An adaptive method is proposed also based on perceptual criteria that guarantees the invisibility of the watermark and avoids the deterioration of the image. Signature detection is done via hypothesis testing, without to use any information from the original image. The watermarks embedded by the proposed method are very resistant to JPEG and other frequently used compression. Experimental results using real image data verify the effectiveness of the method.

I INTRODUCTION

The use of digitally formatted image and video information is rapidly increasing with the development of multimedia broadcasting, network databases and electronic publishing. This evolution provides many advantages such as easy, fast and inexpensive duplication of products. However it also increases the potential for unauthorized distribution of such information, and significantly increases the problems associated with enforcing copyright protection [1, 2, 3, 4].

Digital watermarking has been proposed as a means to identify the owner and distribution path of digital data. Digital watermarks address this issue by embedding owner identification directly into the digital data itself. The information is embedded by making small modifications to the data (pixels in case of images or video). When the ownership of an image is in question, the watermark information can be extracted to completely characterize the owner or distributor of the data. To be useful, a watermark must be perceptually invisible, statistically undetectable, robust to distortions applied to the host images or video and able to resolve multiple ownership claims.

Among the multimedia data, images and video are certainly the most difficult ones to protect because of the numerous processing operations they may undergo. Many algorithms have recently been proposed for image and video copyright protection. Some techniques modify spatial / temporal data samples while others modify transform coefficients. However, research on copyright protection of images is still in its early stages and none of the existing methods is totally effective against attacks.

In this paper we extend the algorithm proposed in [1] to create signatures that are robust to JPEG and subband image compression as well as lowpass filtering. We propose the adaptation of the watermark into the lowpass information of the images. This is motivated by the fact that the lowpass coefficients are quantized very finely compared to all the other subband or DCT coefficients and in fact are often transmitted losslessly. An adaptive method is also proposed based on perceptual criteria that guarantees the invisibility of the watermark and avoids the deterioration of the image.

II SIGNATURE CASTING IN THE LOWPASS TRANSFORM COEFFICIENTS

Many techniques have been proposed in the literature for watermark embedding in the DCT or in general in the transform domain. In these techniques the watermark information is usually embedded in the AC coefficients of the Discrete Cosine transformed data. This affects the performance of these techniques when the image is compressed, since the watermark is in general a low-power signal which is very vulnerable to quantization noise.

For watermarking in the DCT domain, the input image is first divided into 8×8 blocks, and the DCT of each block is determined. Each 8×8 DCT block may be treated as a three level depth tree of subband transform coefficients. This equivalence is clear, when coefficients with the same index from all DCT blocks are grouped together and scanned, starting from the DC coefficients.

Thus, transforming an image with an 8×8 DCT can be seen to produce hierarchical data equivalently with a subband transform of 64 frequency bands.

The DCT coefficients of the block (i,j) are determined by the following equation:

$$F_{ij}^{D}(u,v)=\frac{1}{4}C(u)C(v)\sum_{n=0}^{7}\sum_{m=0}^{7}f_{ij}(n,m)\cos\frac{(2n+1)u\pi}{16}\cos\frac{(2m+1)v\pi}{16}, \tag{1}$$

$$u,\ v=0,\dots,7,\ \ i=0,\dots,\frac{N}{8}-1,\ \ j=0,\dots,\frac{M}{8}-1,$$

where $F_{ij}^{D}(u,v)$ are the DCT coefficients of the (i,j) block, $f_{ij}(n,\ m)$ is the luminance value of the pixel (n,m) of the (i,j) block, $N\times M$ are the dimensions of the image, and

$$C(u)=\begin{cases}\frac{1}{\sqrt{2}} & \text{if} \quad u=0\\ 1 & \text{if} \quad u\neq 0\end{cases}. \tag{2}$$

The relation for the lowpass image $LP(i,j)$ in case of DCT or subband transform is :

$$LP(i,j)=\begin{cases}F_{ij}^{D}(0,0) & \textit{for DCT}\\ F_{00}^{S}(i,j) & \textit{for subband transform}\end{cases} \tag{3}$$

where $F_{uv}^{S}(i,j)$ is the (i,j) coefficient of the (u,v) subband in case of subband transform and $i=0,\dots,\frac{N}{8}-1$, $j=0,\dots,\frac{M}{8}-1$.

Any image watermarking technique can then be used to embed authorization information in the lowpass image $LP(.,.)$. In this paper we have used an adaptive extension of the technique presented in [1] which is based on hypothesis testing.

III ADAPTIVE WATERMARK EMBEDDING IN MULTIRESOLUTION DATA

To produce the watermark pattern $W(.,.)$ a binary pattern $S(.,.)$ of dimension $(\frac{N}{8}\times\frac{M}{8})$ is used, i.e. of the same size with the lowpass image $LP(.,.)$ formed from the DC coefficients of the transform. The binary pattern S is determined by

$$S=\{S(i,j), i\in\{0,\dots,\frac{N}{8}-1\}, j\in\{0,\dots,\frac{M}{8}-1\}\}\ , \quad s_{ij}\in\{-1,1\}\ , \tag{4}$$

where

$$S(i,j)=\begin{cases}1 & \text{if} \quad \lambda>0.5\\ -1 & \text{if} \quad \lambda<0.5\end{cases}, \tag{5}$$

where the parameter $\lambda\in[0,\ 1]$ assumes its value from a pseudo-random real number generator sequence of dimension $\frac{N}{8}\times\frac{M}{8}$. This sequence is completely specified by two integer values : a) the seed r which initializes the pseudo-random number generator and generates a random sequence and b) a point g in this random sequence that initializes the watermark generation sequence. Each initializing value (seed) will typically result in a different random sequence, and each g will define a different starting point. The same initializing value of seed will always return the same random sequence, however.

Using $S(.,.)$ we can split the lowpass image $LP(.,.)$ in two subsets A, B according to :

$$\begin{aligned}A&=\{LP(i,j),\ i,j:\ s_{ij}=1\}\ ,\\ B&=\{LP(i,j),\ i,j:\ s_{ij}=-1\}\ ,\end{aligned} \tag{6}$$

An adaptive watermarking technique is proposed i.e. a technique that determines g based on the statistics of the examined image. More specifically, for the specific seed r we select from a finite number of possible values for g, the one that satisfies :

$$A,B:(\bar{a}-\bar{b})\rightarrow \text{ maximum} \tag{7}$$

i.e. maximizes the difference of the sample means $\bar{a}$, $\bar{b}$ of the sets A and B in order to increase the performance of the watermark detection procedure.

To initialize the hypothesis testing procedure, we define the random variable $\bar{\eta}$, as :

$$\bar{\eta}=\bar{a}-\bar{b}\ . \tag{8}$$

For the estimation of the mean value $\bar{\eta}_0$ and the standard deviation $\hat{\sigma}_{\bar{\eta}}$ of the random variable $\bar{\eta}$ a very large number of sample values of $\bar{\eta}$ is computed, by randomly selecting a very large number of seeds which generates a corresponding large number of watermarks. The statistics of $\bar{\eta}$ are then estimated from the above ensample of watermarks.

The test statistic that is used for hypothesis testing is [1]:

$$q=\frac{\bar{\eta}-\bar{\eta}_0}{\hat{\sigma}_{\bar{\eta}}}\ . \tag{9}$$

The value of k that minimizes the summation of both errors (Type I and Type II [5]), of the hypothesis testing procedure, is given by [1] :

$$k=2\hat{\sigma}_{\eta}t_{1-a}\ , \tag{10}$$

where t_{1-a} is a threshold corresponding to the desired degree of certainty $d=(1-a)$.

The insertion of the watermark to the lowpass information of the signal has the drawback that it may produce visible distortions in the image, especially in its homogeneous areas. In order to cope with this problem, the embedding of the watermark is performed mainly into coefficients of blocks having sufficient texture information, i.e. blocks whose AC energy is greater than a specific threshold e_t. The AC coefficient energy of each block (i,j) is computed as follows :

$$Q_{ij}=\sum_{u,v\in\{0,\dots,7\}:u+v\neq 0}F_{ij}(u,v)^2. \tag{11}$$

in case of DCT and

$$Q_{ij}=\sum_{u,v\in\{0,\dots,7\}:u+v\neq 0}T_{ij}(u,v)^2. \tag{12}$$

where $T_{ij}(u,v)$ is given by

$$T_{ij}(u,v) = F^S_{uv}(i,j) \tag{13}$$

in case of subband transform. Based on this energy, a homogeneity detection bitmap $E(.,.)$ of dimension $\frac{N}{8} \times \frac{M}{8}$ can be defined, by comparing the energy Q_{uv} of each block with a threshold e_t :

$$E(i,j) = \begin{cases} 1 & \text{if} \quad Q_{ij} \geq e_t \\ 0 & \text{if} \quad Q_{ij} < e_t \end{cases} \tag{14}$$

Note that even if the bitmap $E(.,.)$ is depended on the image and will only be used during the watermark embedding procedure for controlling the amplitude of the watermark to be embedded.

The watermark is then embedded in $LP(.,.)$ by modifying each of the mean values $\bar{a}$, $\bar{b}$ of the ensamples A and B by the value $\frac{k}{2}$ in average. In this way, two new sets C and D are created, defined as follows :

$$C = \{LP(i,j) + \frac{k_{ij}}{2},\ i,j : LP(i,j) \in A\} \tag{15}$$

$$D = \{LP(i,j) - \frac{k_{ij}}{2},\ i,j : LP(i,j) \in B\}, \tag{16}$$

where,

$$\frac{k_{ij}}{2} = \begin{cases} \frac{k_{max}}{2} & \text{if} \quad E_{ij} = 0 \\ \frac{\bar{k}_{max}}{2} & \text{if} \quad E_{ij} = 1 \end{cases}, \tag{17}$$

where $\frac{k_{max}}{2}$ is the biggest quantity that must be considered for the modification of the lowpass coefficients that belong in homogeneous blocks, in order to avoid visible artifacts in the watermarked image. The parameter $\frac{\bar{k}_{max}}{2}$ represents the necessary quantity that must be considered for the modification of the lowpass coefficients belonging in non-homogeneous blocks, so the average modification of the mean values of the sets A, B to be approximately, $\frac{k}{2}$. Based on the above analysis it is obvious that the final watermark signal embedded in the image $W(.,.)$ is a 2D signal of the form :

$$W(i,j) = \begin{cases} \frac{k_{ij}}{2}, & \text{if } s_{ij} = 1 \\ \frac{-k_{ij}}{2}, & \text{if } s_{ij} = -1 \end{cases}. \tag{18}$$

IV WATERMARK DETECTION

The watermark detection algorithm is again based on the hypothesis testing theory. The test statistic used is the random variable q [5] defined from (9). The hypothesis testing procedure is based on the mean value and examines the distance of the sample value of the random variable $\bar{\eta}$ from its mean value $\bar{\eta}_0$, i.e. if the image is watermarked with a specific known watermark, the value of $\bar{\eta}$ will be close to $k + \bar{\eta}_0$.

Specifically the statistical test is based on the comparison of q with a specific threshold t_{1-a}.

- If $q > t_{1-a}$ the image is considered watermarked with the specific watermark.
- If $q < t_{1-a}$ we decide that the image is not watermarked with the specific watermark.

V EXPERIMENTAL RESULTS

For the experimental evaluation of the proposed method the monochromatic image "Lenna" (512×512) was used. Firstly, the estimation of the statistics of the random variable $\bar{\eta}$ was examined. The value of $\bar{\eta}$ was computed by randomly selecting a very large number of seeds which generated a corresponding large number of watermarks. The statistics of $\bar{\eta}$ were then computed from the above ensample of watermarks. The results, in case of DCT and subband data, are illustrated in Table 1.

Domain	Number of seeds	Sample Mean	Sample Variance	k
DCT	40	46.95	2.70	22
Subband Haar	40	46.83	2.67	22
Subband [6]	40	47.07	3.00	24

Table 1: Statistics of the watermarked images, when applying the algorithm in DCT and subband coefficients. The value of k was determined for 99.9999% degree of certainty.

By observing this Table it is easily shown that in order to achieve a probability of correct detection equal to 99.9999%, the difference of the mean values of the sets A, B should be increased by $k = 22$ in case of DCT, $k = 22$ in case of subband transform using the Haar basis filters, and $k = 24$ in case of subband transform using the best filters in [6].

Figure 1: Homogeneity map for image "Lenna".

In terms of visual inspection in case of DCT, Figure 1 shows the segmentation map into homogeneous and non-homogeneous regions interleaved with the image, while Figure 2 shows the watermarked image. As it is easily seen, using the above segmentation the watermark is almost invisible.

For the experimental evaluation of the probability of correct watermark detection an ensample of $N = 1000$

Figure 2: The watermarked version of the image "Lenna". The PSNR between the original and watermarked image is 44.6 dB.

watermarked versions of the original image "Lenna" was created, corresponding to different seeds. These images were compressed using JPEG with various compression ratios. The results of the application of the watermark detection algorithm are shown in Figure 3. The results are compared with that of [3], where a robust signature design method was used (RSDM).

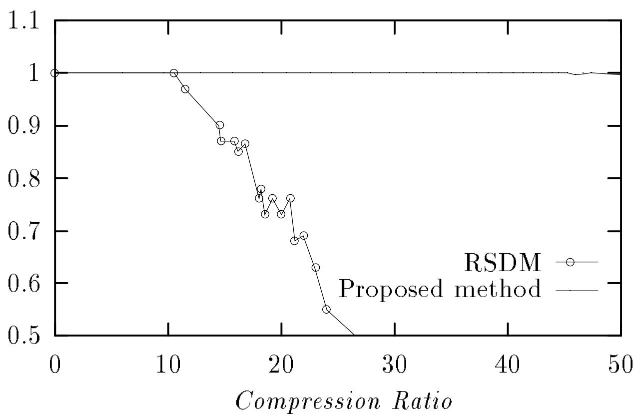

Figure 3: Experimental results that verifies the robustness of the proposed method against JPEG compression.

Similarly for the experimental evaluation of the false detection probability a watermarked version of the original image was initially created, corresponding to a value of seed s. Then, a large number of different watermarks ($N = 1000$), corresponding to seeds with values $f \neq s$, were tried to be detected in compressed versions of the originally watermarked image. The false detection probability is defined as the percentage of false watermarks that are recognized by the proposed algorithm as valid. The results of the application of the false probability detection algorithm are shown in Figure 4. As seen, the results are again encouraging since errors may occur only in very large compression ratios.

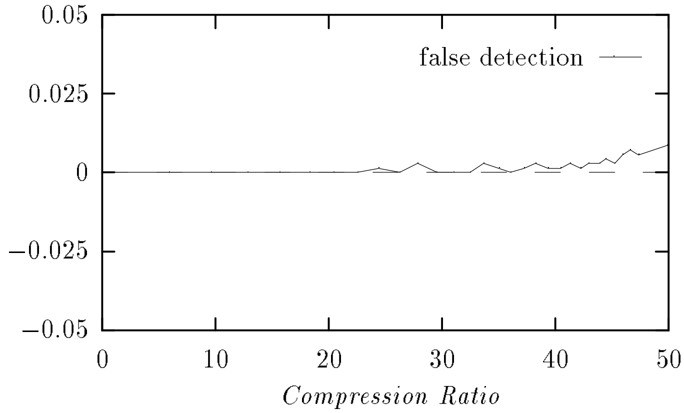

Figure 4: The "false detection probability" as a parameter of the compression ratio.

Finally the stamina of the algorithm in lowpass procedures was also tested. Specifically, an ensample of $N = 200$ watermarked versions of the original image was created, and the watermark detection was tried after compressing them with JPEG and applying mean and median filtering (3×3). The proposed method was very robust even against this procedure since errors occured only in case of a compression ratio larger than 30:1 for mean filtering and 40:1 for median filtering.

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