IMAGE WATERMARKING IN THE JOINT SPATIO-FREQUENCY DOMAIN USING DISCRETE EVOLUTIONARY TRANSFORM

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ABSTRACT

Watermarking techniques are proposed as a solution to copyright protection of digital media files. In this work, a new and powerful watermarking method that is based on spatio-frequency (SF) representations is presented. We use the discrete evolutionary transform calculated by the Gabor expansion to represent an image in the SF domain. A watermark is embedded onto selected cells in the joint SF domain. Hence by combining the advantages of spatial and spectral domain watermarking methods, a robust and perceptual method is presented.

1. INTRODUCTION

Recently, the production, distribution, and use of digital media has become very popular. Although these products have the advantages of high quality, ease of modification and quality duplication, they introduce the problems of copyright protection issues because they can be easily copied and altered. Watermarking techniques are proposed as a solution to copyright protection problems of digital media files. The basic idea in watermarking is embedding a secret data into a multimedia file. In recent research, new methods are proposed to watermark audio, image and video files.

In digital watermarking a specific information called watermark is embedded in a multimedia file in such a way that it can be detected or extracted when necessary. The watermark may contain information about the digital object as well as information about the user or owner. As for image and video files, the watermark is usually another image or signature logo. The watermarking may be embedded so that it is either visible or invisible.

The principle of watermarking is to embed a digital code (watermark) within the host multimedia document, and to use such a code to prove ownership, to prevent illegal copying, or simply to give some indications about the watermarked data or to enable the access to enhanced versions of the content or to additional services. The watermark code is embedded by making imperceptible modification to the original data. A watermarking algorithm in general consists of three basic components: (i) watermark, (ii) Encoder (watermarking algorithm), (iii) Decoder (detection or extraction algorithm). To be useful a digital watermarking system must satisfy same basic requirements. First of all, the embedded watermark should be perceptually invisible. In other words, its presence should not affect the image quality. Moreover, the embedded watermark should be robust against the common signal processing manipulations like AWGN, Salt&Pepper noise, filtering, JPEG Compression, rotation and cropping.

Image watermarking algorithms are mainly concentrated on spatial or spectral domains. Although successful methods have been presented using both approaches, they also have limitations and weaknesses. In the spatial domain, the image area where watermark is embedded is chosen based on the texture of the original image [1, 2]. In the spectral approach, watermark is embedded in a transform domain using discrete cosine transform, discrete wavelet transform, etc. For an invisible and robust watermarking, the watermark is embedded into middle frequencies range [3, 4, 5]. Watermarking in the frequency domain has advantages in terms of robustness, but there are limitations as invisible embedding may be difficult. Some new techniques are introduced by combining the advantages of both spatial and spectral domains for robust and invisible watermarking. This can be done using joint SF representations of images [6, 7]. Watermarking in the joint SF domain provides flexibility in terms of how much watermark will be embedded in which image region, and in what frequency band.

In this work, we present a new image watermarking algorithm based on a discrete evolutionary transform (DET) which provides a time-frequency (TF) representation for sequences. We introduce watermark embedding or encoding as well as detection and extraction algorithms in the SF domain.

2. SPATIO-FREQUENCY ANALYSIS BY DISCRETE EVOLUTIONARY TRANSFORM

In the following we briefly explain the Discrete Evolutionary Transform (DET) as a tool for the time–frequency representation of image sequences.

A non-stationary signal, $x(n), 0 \leq n \leq N-1$, may be represented in terms of a time-varying kernel $X(n,\omega_k)$. The TF discrete evolutionary representation of $x(n)$ is given by [8],

$$x(n) = \sum_{k=0}^{K-1} X(n,\omega_k) e^{j\omega_k n}, \tag{1}$$

where $\omega_k = 2\pi k/K$, K is the number of frequency samples, and $X(n,\omega_k)$ is the evolutionary kernel. The evolutionary spectrum is obtained from this kernel as $S(n,\omega_k) = \frac{1}{K}|X(n,\omega_k)|^2$. The discrete evolutionary transformation (DET) is obtained by expressing the kernel $X(n,\omega_k)$ in terms of the signal. This is done by using conventional signal representations [8]. Thus, for the representation in (1), the DET that provides the evolutionary kernel $X(n,\omega_k), 0 \leq k \leq K-1$, is given by

$$X(n,\omega_k) = \sum_{\ell=0}^{N-1} x(\ell) \mathrm{W}_k(n,\ell) e^{-j\omega_k \ell}, \tag{2}$$

where $W_k(n,\ell)$ is, in general, a time and frequency dependent window. Details on how the windows can be obtained from either the Gabor expansion that uses non-orthogonal windows or the Malvar wavelets that uses orthogonal basis are given in [8]. The multi–window Gabor expansion is given by [9]

$$x(n) = \frac{1}{I}\sum_{i=0}^{I-1}\sum_{m=0}^{M-1}\sum_{k=0}^{K-1} a_{i,m,k}\ h_i(n-mL)\ e^{j\omega_k n} \tag{3}$$

where $\{a_{i,m,k}\}$ are the Gabor coefficients, and $\{h_{i,m,k}\}$ are the Gabor basis functions defined as:

$$h_{i,m,k}(n) = h_i(n-mL)\ e^{j\omega_k n} \tag{4}$$

and the synthesis window $h_i(n)$ is obtained by scaling a unit–energy mother window $g(n)$ as

$$h_i(n) = 2^{i/2}\ g(2^i n),\ i = 0,1,\cdots,I-1.$$

The multi-window Gabor coefficients are evaluated by

$$a_{i,m,k} = \sum_{n=0}^{N-1} x(n)\ \gamma_i^*(n-mL)\ e^{-j\omega_k n}, \tag{5}$$

where the analysis window $\gamma_i(n)$ is solved from the bi-orthogonality condition between $h_i(n)$ and $\gamma_i(n)$ [9]. Hence by comparing the representations of the signal in (3) and (1) we obtain the DET kernel as

$$X(n,\omega_k) = \frac{1}{I}\sum_{i=0}^{I-1}\sum_{m=0}^{M-1} a_{i,m,k}\ h_i(n-mL). \tag{6}$$

Substituting for the coefficients $\{a_{i,m,k}\}$, we obtain that

$$X(n,\omega_k) = \sum_{\ell=0}^{N-1} x(\ell)\ W(n,\ell)\ e^{-j\omega_k \ell}, \tag{7}$$

where we defined a time-varying window as

$$W(n,\ell) = \frac{1}{I}\sum_{i=0}^{I-1}\sum_{m=0}^{M-1} \gamma_i^*(\ell-mL)\ h_i(n-mL).$$

Then the evolutionary spectrum of $x(n)$ is given by

$$S(n,\omega_k) = \frac{1}{K}\ |X(n,\omega_k)|^2.$$

We should mention that above evolutionary spectral estimate is always non-negative, and normalizing the $W(n,\ell)$ to unit energy, the total energy of the signal is preserved thus justifying the use of $S(n,\omega_k)$ as a TF energy density for $x(n)$. Furthermore, DET provides a linear signal representation where the sequence may be obtained from the TF representation much easier than it is with the bilinear TF representations such as Wigner distribution [9]. Hence DET is appropriate for watermarking applications in the SF domain where embedding and extracting a watermark will be easily implemented using linear operations.

3. DET-BASED WATERMARK EMBEDDING

In our SF based watermarking approach, the rows of the image to be watermarked are considered as one dimensional sequences and transformed into the joint SF domain. There are methods to represent two dimensional images in the SF domain, but computational complexity and the dimensionality problems make them difficult to use in watermarking applications [6]. Recently new methods are presented where TF distributions (TFDs), usually the Wigner distribution, of each row of an image is used for embedding a watermark in the joint TF domain [7, 10]. However, synthesis of a sequence from its modified bilinear TFD is generally a difficult problem. Hence we propose a new SF domain watermarking where we use the linear DET explained above to embed the watermark into each row of the image. Then the watermarked rows are easily obtained by the inverse transformation.

Let $I(x,y)$, $0 \le x,\ y \le N-1$, be the original image and $w(n)$, $0 \le n \le N-1$ be the watermark sequence. First, the DET of the watermark sequence, $X_W(y,\omega_k)$, is obtained. Then, the DET of row x of the image,

$$X_I(y,\omega_k) = \sum_{\ell=0}^{N-1} I(x,\ell)\ W(y,\ell)\ e^{-j\omega_k \ell} \tag{8}$$

$0 \le y,k \le N-1$, is obtained. Proposed watermark embedding algorithm in the SF domain is done by adding a weighted DET kernel of the watermark onto $X_I(y,\omega_k)$ as,

$$\hat{X}_I(y,\omega_k) = X_I(y,\omega_k) + T_I(y,\omega_k)X_W(y,\omega_k). \tag{9}$$

Here $T_I(y,\omega_k)$ represents the SF domain weighting matrix for the row x [10], and it is calculated by:

$$T_I(y,\omega_k) = \begin{cases} \frac{X_I(y,\omega_k)}{max\{X_I(y,\omega_k)\}} & ,\omega_1 \le |\omega_k| \le \omega_2 \\ 0 & ,\text{otherwise} \end{cases} \tag{10}$$

The weighting matrix is chosen such that the watermark is embedded into the middle frequencies range. ω_1 and ω_2 determine the range of frequencies where the watermark is embedded, and they are chosen as 0.3π and 0.6π respectively in this work. Therefore, a robust and perceptual watermarking is achieved. Watermarked image row, $\hat{I}(x,y)$, is obtained from the watermark embedded SF matrix, $\hat{X}_I(y,\omega_k)$, by the inverse DET (IDET):

$$\hat{I}(x,y) = \sum_{k=0}^{K-1} \hat{X}_I(y,\omega_k)\ e^{j\omega_k y} \tag{11}$$

On the other hand, substituting (9) into (11), the embedding algorithm can be obtained in the spatial domain as follows:

$$\begin{aligned} \hat{I}(x,y) &= \sum_{k=0}^{K-1} [X_I(y,\omega_k) + T_I(y,\omega_k)X_W(y,\omega_k)]\ e^{j\omega_k y} \\ &= I(x,y) + \sum_{k=0}^{K-1} T_I(y,\omega_k)X_W(y,\omega_k)\ e^{j\omega_k y} \end{aligned} \tag{12}$$

The embedding process is repeated for all rows of the image. The second term of the last equation can be viewed as a new image which is obtained from the modified DET kernel of the watermark

$$I_W(x,y) = \sum_{k=0}^{K-1} T_I(y,\omega_k) X_W(y,\omega_k)\, e^{j\omega_k y}. \quad (13)$$

So, the embedding algorithm can be considered as the combination of two images in the spatial domain:

$$\hat{I}(x,y) = I(x,y) + I_W(x,y) \quad (14)$$

As can be seen in (13), the SF dependence of the watermarking algorithm is ensured through the SF dependent weighting matrix.

4. WATERMARK DETECTION AND EXTRACTION

In digital watermarking studies, methods have been presented for detection and extraction of the watermark by assuming that some information used in the embedding is known to the detector [10]. However, there are some work where blind detection is achieved without using any extra information. In practical applications such as copyright protection, the most important goal is the detection of watermark existence even after the watermarked image is attacked. At detection or extraction stages of a copyright protection algorithm, the original image as well as the watermarked image are known. In our study, we assume that we have the original and the watermarked images and try to extract the watermark. It can be seen from (14), that the difference between the watermarked and original images gives us $I_W(x,y)$ matrix. The weighting matrix $T_I(y,\omega_k)$ for any row of the original image can be obtained at the detection part as in (10). The DET of the watermark can be extracted by using the same row of the $I_W(x,y)$ matrix as,

$$X_W(y,\omega_k) = \frac{\hat{X}_I(y,\omega_k) - X_I(y,\omega_k)}{T_I(y,\omega_k)} \quad (15)$$

Any row of the image can be used for watermark detection, because the same watermark is embedded into all rows of the image. This makes the proposed method very robust against attacks.

5. SIMULATIONS

The proposed watermarking method was tested on some commonly used images (Lena, Baboon, Boats, and Barbara) and the detection performance was investigated. Watermark is chosen as a sequence that is obtained by coding an identity information. The original and the watermarked Baboon images can be seen in Fig.1. The difference between the original and the watermarked images is given in Fig.2. Notice that the watermark embedding causes some changes on the edges of the image. It is seen that there is not any visible difference between the watermarked and the original images. PSNR for the baboon image is equal to 50.66dB, and it is greater than 50dB for the other images.

The performance of the method was also tested under different attacks for above images. Additive white Gaussian noise (AWGN), salt & pepper (SP) noise, Wiener filtering (WF), Median filtering (MF), JPEG Compression, and rotation attacks are used. The normalized correlation between the extracted and the original watermarks are calculated and presented for all images in Table 1.

6. CONCLUSIONS

In this work, a new watermarking algorithm that is based on a spatio-frequency transform is proposed. Discrete evolutionary transform is used for the SF representation of the rows of an image. Watermark embedding algorithm is developed to combine the advantages of both spatial and spectral domain watermarking techniques. Thus, a better robustness than methods that use only spatial or spectral domain embedding is achieved. Another advantage of the proposed method is that the watermark is embedded into all rows of the image. At the detection end, the watermark can be extracted by using the original image. The performance of the method is tested under several attacks, and observed that it is successful against additive noise and cropping. Furthermore, the proposed algorithm which is based on a linear representation is computationally simpler than other bilinear TFD based methods [7, 10]. The investigation of the different embedding methods that use the advantages of the SF domain and more successful than this method will be the next step of this work.

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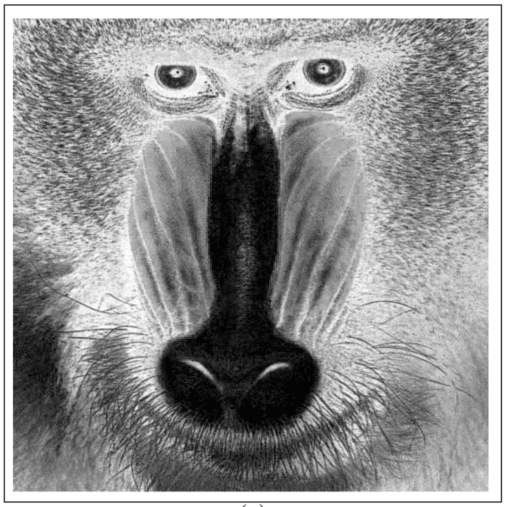
Table 1: Normalized correlations under different attacks.

Image	Lena	Baboon	Boats	Barbara
AWGN (σ^2=0.005)	0.8534	0.7635	0.8860	0.7745
AWGN (σ^2=0.010)	0.8246	0.7603	0.8355	0.7445
AWGN (σ^2=0.015)	0.7833	0.7331	0.8019	0.7322
AWGN (σ^2=0.020)	0.7599	0.7160	0.7858	0.7170
AWGN (σ^2=0.025)	0.7511	0.7059	0.7470	0.7036
SP Noise (Density=0.02)	0.9009	0.8797	0.9595	0.8881
SP Noise (Density=0.04)	0.8715	0.8590	0.8939	0.8654
SP Noise (Density=0.06)	0.8677	0.7967	0.8352	0.8257
SP Noise (Density=0.08)	0.7808	0.7791	0.7799	0.7805
SP Noise (Density=0.10)	0.8006	0.7629	0.7379	0.7479
WF (3x3)	0.9425	0.8257	0.9788	0.8696
WF (4x4)	0.9283	0.7966	0.9658	0.8425
WF (5x5)	0.9017	0.7681	0.9438	0.8177
WF (6x6)	0.8571	0.7547	0.9171	0.7908
WF (7x7)	0.9345	0.7929	0.9617	0.8159
MF (3x3)	0.1440	0.1686	0.1661	0.1523
MF (6x6)	0.0700	0.0934	0.0907	0.0878
MF (9x9)	0.1150	0.0782	0.0908	0.0748
MF (12x12)	0.1059	0.0686	0.0685	0.0545
MF (15x15)	0.1195	0.0645	0.0761	0.0484
JPEG (Q=10%)	0.5681	0.5524	0.5586	0.4712
JPEG (Q=30%)	0.7770	0.7205	0.8156	0.6603
JPEG (Q=50%)	0.8230	0.7542	0.8843	0.7044
JPEG (Q=70%)	0.8428	0.7736	0.9081	0.7349
JPEG (Q=90%)	0.8761	0.7827	0.9277	0.7863
Rotation (5^o)	0.1216	0.0572	0.0700	0.0605
Rotation (10^o)	0.0610	0.0713	0.0892	0.0513
Rotation (15^o)	0.0916	0.0513	0.0623	0.0831
Rotation (20^o)	0.0711	0.0743	0.0661	0.0457
Rotation (25^o)	0.0523	0.0526	0.0660	0.0728


(a)

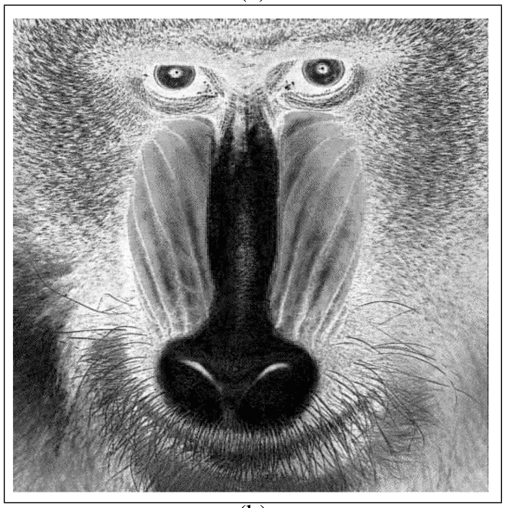

(b)

Figure 1: a) Original b) watermarked Baboon images.

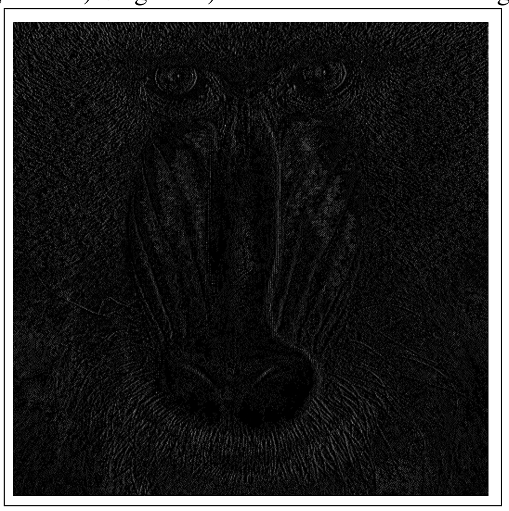


Figure 2: Difference between the original and the watermarked baboon images.