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WATERMARKING OF DIGITAL IMAGES BASED ON PRINCIPAL COMPONENT ANALYSIS

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Abstract- **A new domain PCA-based approach to watermarking is presented. This method is applied to digital images to embed and detect a watermark. The performance of PCA approach is compared to traditional frequency domain watermark models. Simulation shows the performance of the proposed method with excellent result against image cropping and robustness against some attacks such as additive noise, filtering, and jpeg compression.**

1. INTRODUCTION

With development of the Internet, digital networks and multimedia technologies, one can make quickly and inexpensively exact copies of a multimedia product. Consequently, digital watermarking is developed for multimedia copyright protection purposes. Image watermarking techniques proposed so far can be divided into two main groups: those which embed the watermark in the spatial domain and those operating in a transform frequency domain (DCT, FFT, and DWT) [4].

The research in digital image watermarking is first developed in spatial domain. The technique, however, can embed only a small number of bits and is not to be robust against many attacks. The frequency domain techniques embed watermark data by changing a frequency component value by an orthogonal transformation. The technique can embed a larger number of bits with invisibility, and thus it can be employed with common image transforms, such as discrete cosine transform (DCTs) [2] [3], Fourier transform [7], and the wavelet transform [5] [6]. An advantage of the frequency domain-based technique over the spatial domain approaches is that watermark casting and detection can be done with compressed images and it is possible to insert watermarks into jpeg images. The frequency-domain watermarking methods are relatively robust to attacks such as noise, common image processing and jpeg compression, compared to the spatial domain method. Almost all digital image watermark techniques are based on those domains to embed and detect watermark.

In this paper we present a novel watermarking domain based on PCA [1], and the method uses PCA as a transformation and watermarks are added in PCA domain. Experiments show that the method is robust enough for common attacks such as image cropping, image compression (JPEG) image enhancement (low pass filter, median filter, Gaussian noise) and that the embedded marks are invisible as needed in most practical applications.

2. PCA DOMAIN WATERMARKING

To introduce watermark technique in PCA domain, we first review the basic PCA technique and applied it to digital image watermarking.

A picture I(m,n) with size MxN can be denoted by [I] where m and n take integer values from 0 through M-1 and N-1. We write the transform of the image as:

$$[T(u,v)] = \sum_{m=0}^{M-1} \sum_{n=0}^{N-1} I(m,n)\varphi^{(u,v)}(m,n) \quad (1)$$

where $[\varphi^{(u,v)}]$ is a transformation matrix (basic function), $[T(u,v)]$ the transform of the image. The inverse transformation can be defined as:

$$[I(u,v)] = \sum_{m=0}^{M-1} \sum_{n=0}^{N-1} T(m,n)\varphi^{-1(u,v)}(m,n) \quad (2)$$

where $[\varphi^{(u,v)}]^{-1}$ is the inverse transformation matrix.

It is noted that the discrete Fourier transform uses sinusoidal functions as basic functions, DCT uses cosine functions, and the wavelet transforms uses a particular wavelet as its basic function. The following two steps are applied to an image to find PCA transformation function $[\varphi]$:

Step 1. The image is partitioned in to number-of sub-images. We consider each sub-image like a vector (vector of pixels). Image data vector can be express as: $I=(i_1,i_2,i_2.....,i_m)^T$ where vector i_i is the i-th sub image and T denoted the transpose matrix, each sub-image has n^2 pixels. Each vector i_i has n^2 dimensional.

Step 2. Calculate the covariance matrix C_x of sub-images and the eigenvectors, eigenvalues of the covariance matrix: $C_x = E(I-m_i)(I-m_i)^T$, where $m_i = E(I)$ are mean vector of each sub-vector, we may find the eigenvectors and the corresponding eigenvalues of the covariance matrix C_x , $C_x\Phi = \lambda_x\Phi$. The matrix $[\varphi]$ formed by the eigenvectors $\Phi = (e_1,e_2,e_3,....,e_n)$. Eigenvalues λ, $(\lambda_1 \geq \lambda_2 \geq \lambda_3 \geq ..... \geq \lambda_n)$ and eigenvectors $[\varphi]$ are sorted in descending order, The matrix $[\varphi]$ is an orthogonal matrix called basic functions of PCA.

We then can transform sub-images into uncorrelated coefficients to embed the watermark. The original spectrally correlated image [I] can be decorrelated by the basic function [Φ], and get the eigen image uncorrelated coefficients Y by following equation:

$$Y = \Phi^T I = (y_1, y_2, \ldots\ldots y_n)^T \quad (3)$$

Corresponding to each sub-images in I, $I = (i_1, i_2, i_3, \ldots\ldots, i_m)^T$ the coefficient values in y_i are the principal components. From the eigen-image uncorrelated coefficients corresponding to each sub-pixel we can embed the watermark into some pre-defined components of sub-pixel coefficients.

To retrieve the watermarked image one can apply the following equation:

$$I = (\Phi^T)^{-1} Y = \Phi Y \quad (4)$$

It is noted that in DCT approach method by Cox et al [2] the watermark was added to the n highest magnitude coefficients (excluding DC component), since this method may degrade image quality. More enhancement of this method by Barni et al [3] suggested adding the watermark to a larger number of DCT coefficients which need not be significant. The DCT coefficients in a zig-zag scan and the first 16000 coefficients are left out. The watermark added to next 25000 coefficients. The DFT watermark [7] is embedded in the phase of the DFT which is quite robust against geometric distortion. In the wavelet domain Dugad et al [5] added watermark to the high pass sub-band, the low pass sub–band was left out and picked up the entire coefficient above the predefined threshold T1 in magnitude instead of selecting a fix number of coefficients. The proposed method is based on the properties of PCA transform: a set of coefficients in each sub block coefficients is selected to cast the watermark by modifying the coefficients since watermark is placed in perceptually significant components of the signal.

In this proposed method the watermark consists of pseudo-random number sequence of length M with normally distributed $W = (w_1, w_2, \ldots\ldots w_M)$. The scheme is to embed the watermark into pre-definition components of each PCA sub-block uncorrelated coefficients. The embedded coefficients were modified by the following equation:

$$y' = y + \xi y_i w_i \quad (5)$$

where i = 1, 2…m, ξ is a scaling parameter to control strength of watermark and y' is the watermarked coefficients. The watermarked image I' is received by applying the inverse PCA.

The watermark detection is applied to watermarked image I'. Sub-block uncorrelated coefficients of I' are computed by applying the PCA basic function Φ and the coefficients which were embedded watermarks are selected to generate watermarked coefficient vector $Y^* = (y^*_1, y^*_2, \ldots\ldots y^*_M)$.

The correlation value between the code marked W and possibly corrupted coefficient Y* is calculated to detect the mark:

$$CV = \frac{WY^*}{M} = \frac{1}{M}\sum_{i=1}^{M} w_i y_i^* \quad (6)$$

Watermark correlations are calculated first for mark W, and then for 1000 different random watermarks. The correlation value CV can be used to determine whether a given mark is present or not. For watermark detection, the threshold T is defined by $T = \frac{\xi}{2M}\sum_{i=1}^{M} y_i$.

Like in [3] the threshold which is estimated on the watermarked image is applied to evaluate the decode system.

3. COMPUTER SIMULATION

Embedded data should be able to survive routine attacks such as signal processing image processing operators. Ideally, watermark should be robust with respect to operation such as filtering, cropping, compression, noising..etc. To evaluate PCA domain watermark scheme, we used five standard images : “Aerial”, “Baboon”, “Elaine”, “Man”, and “Peppers” in our experiments. All images are of 512x512 pixels, and n = 8 for each of subblock; for each of them sixteen different watermark random numbers were inserted to the sixteen latest coefficients. To carry out this process the watermark which total length M = 655361 were randomly generated with standard normal distribution.

For PCA domain based watermarking, we found that the robustness can be improved by increasing the strength (the scaling parameters) of the embedded watermark data, but may affect the perceptible degradation of images.

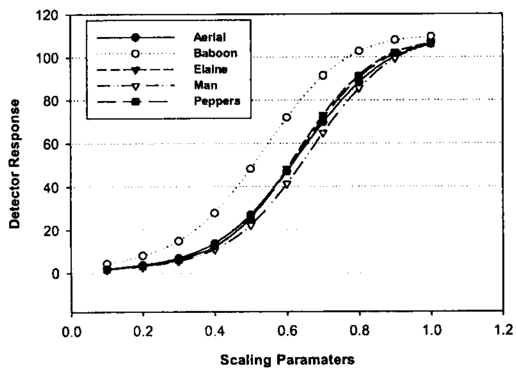


Fig.1. Watermark detector responses corresponding to different scaling parameters

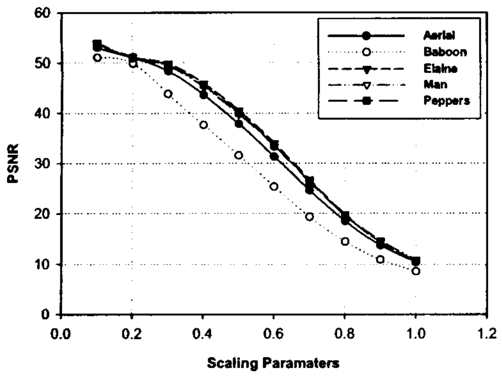


Fig.2. PSRN corresponding to increase of watermark strength

Fig 1 shows watermark detector responses for different scaling parameters to five pictures. Fig 2 shows the change of PSRN following an increase in watermark strength. The correlation shows higher values for a larger scaling parameter. Therefore, to develop a good scheme for robustness of watermarking techniques, the following issues must be considered:

- Robustness depends on the information capacity of the watermark such as the watermark strength/visibility, and the detection statistics.
- Robustness is also influenced by the choice of images (images, size, content, color depth).

In our experiment, the scaling parameter was set $\xi = 0.2$ to avoid the perceptible degradation and ensure the robustness.

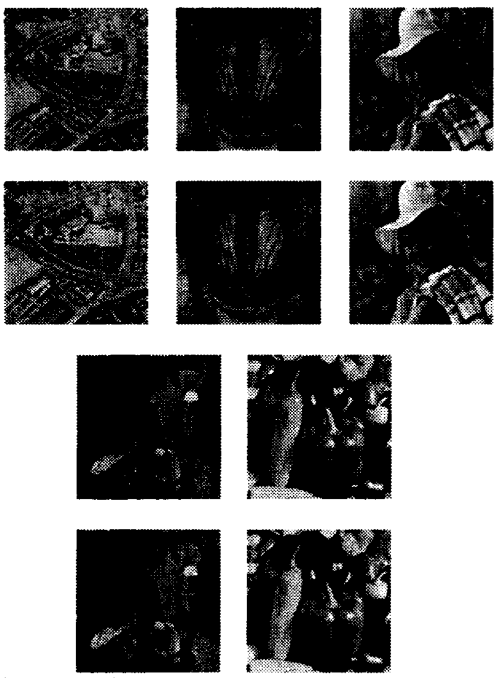


Fig.3. The original and watermarked images "Aerial, Baboon, Elaine, Man, Peppers" corresponding to $\xi = 0.2$

Figure 3 shows five original images and the corresponding watermarked images. Tables 1, 2, and 3 show the results of detector response, threshold, mean square error and PSNR for five pictures with the proposed PCA domain method, the method in [3], and [5]. We can see that our method has stronger detection ability than the method in [3]. The results of the method in [5] are not satisfactory for the image which is composed of a lot of texture and edges. Our method is suitable for both smooth and non smooth images.

Table 1: The detector response, Threshold, MSE and PSNR of the PCA based method (PCA domain).

Pictures	Detector response	Threshold	MSE	PSNR
Aerial	1.33	0.63	0.51	51.02
Baboon	2.8	1.39	0.66	49.94
Elaine	1.11	0.54	0.5	51.13
Man	1.09	0.51	0.5	51.18
Peppers	1.14	0.56	0.5	51.11

Table 2: The detector response, Threshold, MSE and PSNR of the method in [3] (DCT domain).

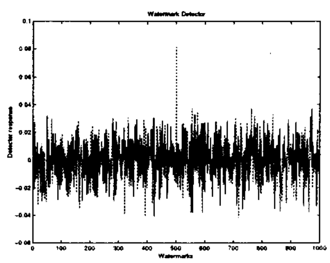
Pictures	Detector response	Threshold	MSE	PSNR
Aerial	3.43	2.48	0.81	49.02
Baboon	3.55	3.12	0.98	48.22
Elaine	1.36	0.83	0.07	59.54
Man	2.49	2.10	0.42	51.94
Peppers	1.34	1.23	0.16	56.05

Table 3: The detector response, Threshold, MSE and PSNR of the method in [5] (DWT domain).

Pictures	Detector response	Threshold	MSE	PSNR
Aerial	0.73	0.23	10.58	38.00
Baboon	1.03	0.28	10.13	38.07
Elaine	0.10	0.03	1.03	47.01
Man	0.48	0.13	5.86	40.47
Peppers	0.19	0.06	2.31	44.49

3.1 Robustness against jpeg compression

(a)



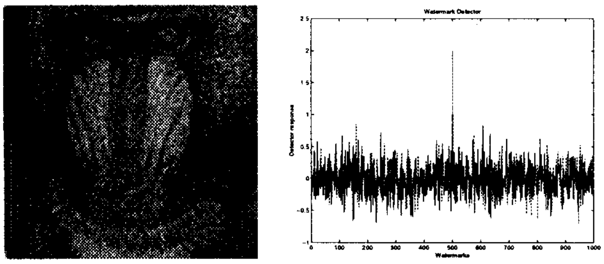
(b)

Fig.4. (a) The watermarked image "Baboon" with jpeg (compression quality 18%), (b) the detector response

The decoder system can detect successfully watermarks when the watermarked images are made lossy compression by the jpeg algorithms. Fig 4(a) shows the watermark image "Baboon" with jpeg (compression quality 18%); and Fig 4(b) shows the detector response for the picture.

3.2 Robustness against Gaussian Noise

Fig 5(a) shows an effect of Gaussian noise addition to the watermarked image "Baboon" with variance σ^2 = 2000 and zero mean; and Fig 5(b) shows the detector response for this corrupted image.

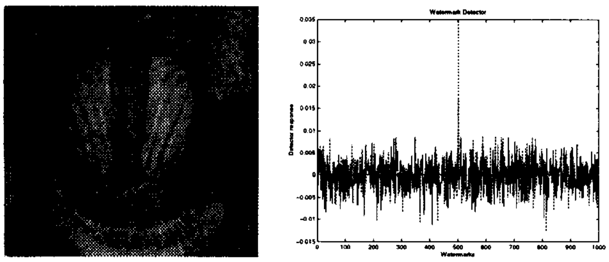


(a) (b)

Fig.5. (a) Gaussian noise addition to the watermarked image "Baboon" with variance σ^2 = 2000 and zero mean; (b) the detector response

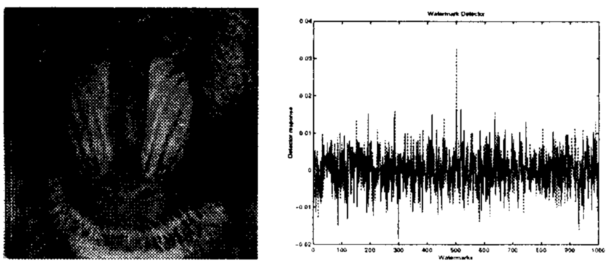
3.3 Robustness against digital filtering

A watermarked image was filtered with low pass and median filters. Figures 6(a) and 7(a) show the watermarked image "Baboon" under filters with window size 5x5, and Figures 6(b), 7(b) show corresponding detector response.



(a) (b)

Fig.6. (a) Watermarked image "Baboon" low passes filtered 5x5, (b) the corresponding detector response

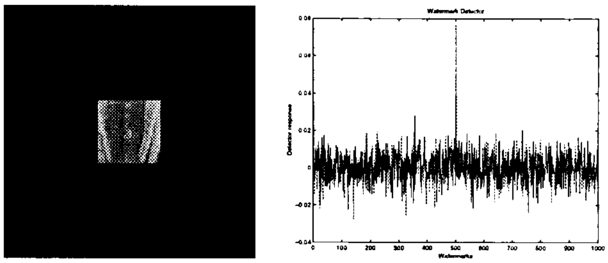


(a) (b)

Fig.7. (a) Watermarked image "Baboon" median filtered 5x5 (b) the corresponding detector response

3.4 Robustness against image cropping

In almost recently research, method in [3] the maximum of cropping area must cover 40% of the original. The proposed system can detect watermarks if the cropped part is at least 10% of the original image, and the system shows excellent results against cropping image attacks. Fig 8(a) shows a 128x128 cropping of "Baboon" image in which only the central part of watermarked image remains; Fig 8(b) shows the detector response.



(a) (b)

Fig.8. (a) 128x128 cropping of "Baboon" image, (b) the detector response

4. CONCLUSION AND REMARK

We introduced a new watermarking based on PCA domain, which differ from the traditional frequency and spatial domain models. Experiment results show that PCA can be used for watermark application, and the proposed PCA scheme is robust against most well known attacks, and that it performed excellent against geometric distortion attacked cropping image.

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