A METHOD FOR DIGITAL IMAGE WATERMARKING USING ICA

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Abstract: Digital watermark technology has been developed quickly during the recent few years and widely applied to protect the copyright of digital image. A digital watermark is the information that is imperceptibly and robustly embedded in the host data such that it cannot be removed. This paper proposes a method based on the independent component analysis (ICA) for the digital image watermarking. The experimental results indicate that the presented approach is remarkably effective in detecting and extracting the digital image watermark. The problem of robust watermarking is also tested to demonstrate the effectiveness of the proposed approach.

1. INTRODUCTION

There has been a rapid growth of digital imagery and digital watermark technology recently. Especially, the recent growth of network multimedia systems has caused problems regarding the protection of intellectual property rights such as the true image, video data and the audio. The types of protection systems involve the use of both encryption and authentication techniques. The watermark is a digital code unremovably, robustly, and imperceptibly embedded in the host data and typically contains information about origin, status, and/or destination of the data [1].

The basic principles of most watermarking methods employ the small and the pseudorandom changes to the selected coefficients in the spatial or transform domain. Most of the watermark detection schemes use some kinds of correlating detector to verify the presence of the embedded digital watermarking [1, 2].

A recently developed method is independent component analysis (ICA), in which the desired representation is the one that minimizes the statistical dependence of the component of the representation. ICA was originally proposed to solve the blind source separation problem. We can recover *N* source signals after they are linearly mixed by an unknown matrix [3]. Applications of ICA can be found in many different areas such as audio processing, biomedical signal processing, image processing and telecommunications [4-6]. ICA can be applied in digital watermark processing [7-8]. In this paper, we attempt to employ the fast fixed-point algorithm, FastICA, to deal with the problem of detection and blind extraction of digital image watermark. The experimental results and the corresponding performance are also shown for watermark processing.

2. DIGITAL WATERMARKING SCHEME

The watermarking procedure is to add a watermark signal to the host data to be watermarked such that the watermark signal is unobtrusive and secure in the signal mixture but can partly or fully be recovered from the signal mixture later on if the correct cryptographically secure key needed for recovery can be provided. Thus, in the generic watermark embedded schemes, the inputs of the system include the original data, the watermark and the optional public or the secrete key. Three main issues in the design of a watermarking system were included：(a) design of the watermark signal to be added to the host signal. (b) design of the embedding method itself that incorporates the watermark signal into the host data, yielding watermarked data. (c) design of the corresponding extraction method that recovers the watermark information from the signal mixture using the key and with the help of the original or without the original.

The secrete or public key is used to enforce the security. The watermark recovery is usually done by some sort of correlation methods, like a correlation or a matched filter. In this paper, two embedding schemes are adopted. The first model is defined as:

$$X = I + aK + bM \tag{1}$$

where both the watermark M and the key K are inserted in the spatial domain of the original image I, and a and b are small weighting coefficients. The second one is defined as:

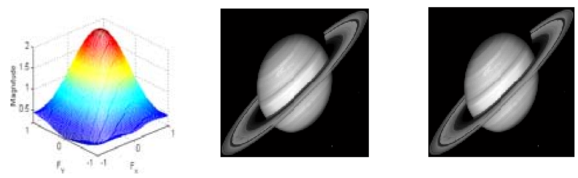
$$X = I + cK + d * M \tag{2}$$

where c is the small filter coefficients and “ * ” denotes the convolution operation. Fig. 1 illustrates an example showing a Saturn image being watermarked by using model 2. Fig. 4 (a) is the frequency response of the specified 2-D filter that is used to convolve with the watermarked image. The original and the watermarked Saturn images are displayed in Fig. 1 (b) and (c), respectively.

For the watermark recovery processing, the private watermarking system is adopted. The system contains both key and the original data for watermark detection and extraction. In general, at least three linear mixtures of the three independent sources are needed for this system. Here, using the key image and the original image, two more mixed images are generated by adding them into the watermarked image X：

$$\begin{aligned} X_1 &= X \\ X_2 &= X + eK \\ X_3 &= X + fI \end{aligned} \tag{3}$$

where e and f are arbitrary real numbers. These three images are rearranged into three rows in one matrix, which is used for de-watermarking process, and will be explained in Section 3.



(a) (b) (c)

Fig. 1. (a) The frequency response of the specified filter, (b) The original image of Saturn, (c) The watermarked image using 2-D filter.

3. FASTICA ALGORITHM

There has been existed several somewhat different versions of the fixed-point algorithm. In our experiments, we use FastICA procedure for watermark detection and blind extraction [9-10]. This method is based on the following two stages. First, PCA whitening process for watermark detection, and next, followed by the FastICA algorithm for the watermark extraction.

Whitening is a linear transformation $\mathbf{A}$ such that, for the given matrix $\mathbf{C}$, we have $\mathbf{ACA}^{\mathrm{T}} = \mathbf{D}$, where $\mathbf{D}$ is a diagonal matrix with positive elements. If principal component analysis is used for whitening, one whitened data matrix can be computed. After PCA whitening, it is convenient to estimate the number of the sources or the independent components from the rank of the diagonal matrix. The FastICA algorithm can be employed by using the fourth-order statistics of the signals [9-10].

4. EXPERIMENTAL RESULTS

Several experiments are carried out to demonstrate the validity and feasibility of the FastICA method for detecting and extracting the digital image watermark. The experimental results based on both model 1 and 2 are shown in Fig. 2 and 3. The watermark extracted from a watermarked Saturn image pixels is shown in Fig. 2 (f) via the model 1. Fig. 3 (f) shows the result of extracting watermark with convolution mixing using the filter and the extracted watermark is given in Fig. 3 (f).

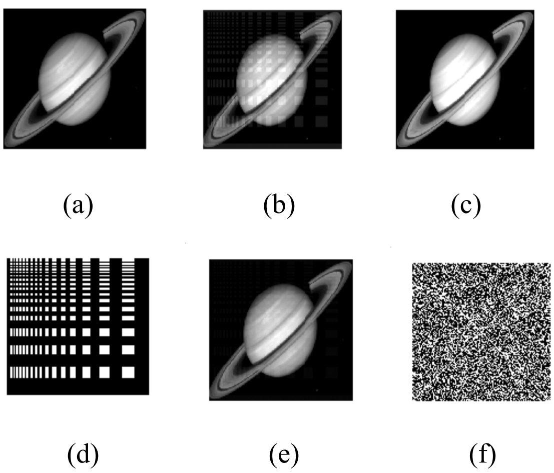


Fig. 2. The results of the watermark extraction for watermark embedding scheme in model 1: (a) The watermarked image, (b) and (c) The generated mixture images, (d) The extracted key, (e) The extracted Saturn image, (f) The extracted watermark.

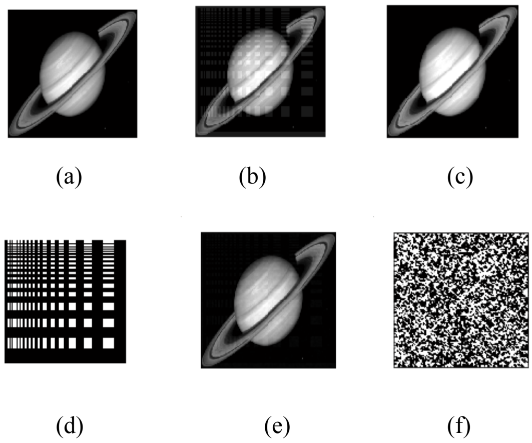


Figure 3. The results of the watermark extraction based on the watermark embedding model 2: (a) The watermark image, (b) and (c) The generated mixture images, (d) The extracted key, (e) The extracted Saturn, (f) The extracted watermark image.

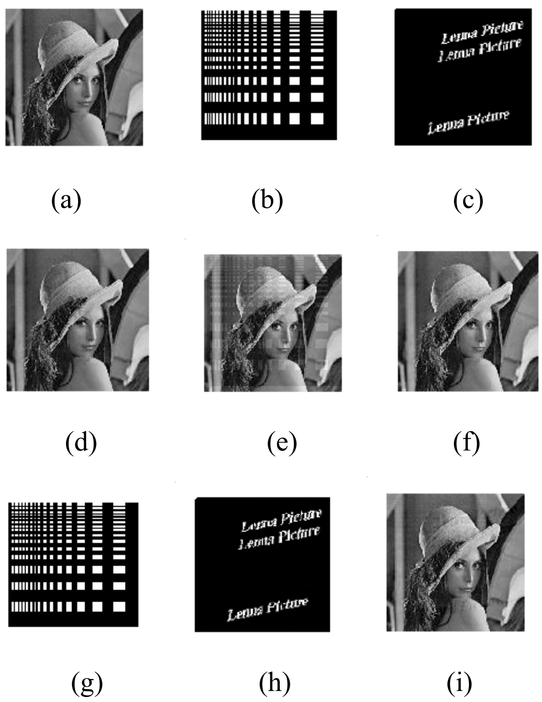


Fig. 4 The watermark extraction results by using the text image as the watermark: (a) The original Lenna image, (b) The key image, (c) The text watermark, (d) The watermarked image, (e) and (f) The generated mixture images, (g) The extracted key, (h) The extracted watermark, (i) The extracted Lenna image.

5. PERFORMANCE ANALYSIS

The performance of the watermark extraction can be evaluated by estimating the normalized correlation coefficient for the extracted watermark and the original embedded watermark:

$$r_m = \frac{\sum_{i=1}^{L} m(i)\hat{m}(i)}{\sqrt{\sum_{i=1}^{L} m^2(i) \sum_{i=1}^{L} \hat{m}^2(i)}} \quad (4)$$

where both m and $\hat{m}$ represent the original and the extracted watermark sequences, respectively, with zero mean value each. L is the total number of the pixels of the image [11-13]. The value range of the normalized correlation coefficients is between minus one and unit. Obviously, the unity holds if the image extracted perfectly matched the original. The minus sign indicates the extracted image is a reverse version of its original image. Table I shows the result of the normalized correlation coefficients between the original and the extracted images for the examples described in Fig. 2 and 3. It can be seen that the FastICA algorithm successfully separates the images from the mixture.

TABLE I: Performance evaluation

Test condition	Correlation coefficient		
	Saturn	Key	Watermark
Model 1	0.9968	0.9972	0.9979
Model 2	0.9952	0.9999	0.9987

Another extraction example employed a text watermark—"Lenna Picture" words. The emebedding scheme isbased on the model (1). The original image is Lenna image, the key image is the same as those in Fig. 5 and 6. The result is shown Fig. 4. The normalized correlation coefficients are also measured against the original images and shown in Table II. The experiments results show that the ICA approach based on the FastICA method provides better estimation behavior for detecting and extracting the digital watermark.

TABLE II: Performance evaluation

Test condition	Correlation coefficient		
	Lenna	Key	Watermark
Model 1	0.9991	0.9987	-0.9995

Robustness against attacks is also a major watermarking requirement. Various attacks were applied to the watermarking images to measure the robustness of the watermarking system. Three attack strategies for our watermarking system include scaling (one of geometric transformations), additive noise and damaging compression (such as JPEG compression). First of all, Fig. 5 illustrates the excellent behavior of the watermark extraction performance against scaling attack with the scaling factor from 0.25 to 3. Based on the experimental result, the extraction performance will be degrade only when the scaling factor becomes very small and the total number of pixels are very few.

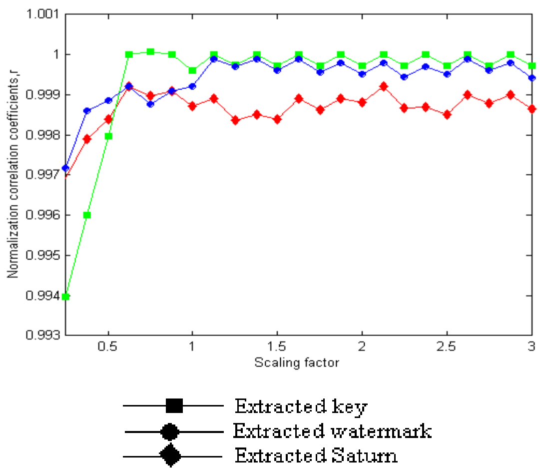


Fig. 5. The results of the correlation coefficient estimation.

Next, the strong noise attacking experiment is also carried out. The mean and variance of the additive noise are set to be zero and 1000, respectively. As shown in Fig. 6, the image appears degraded significantly by comparing with its original image in Fig. 6 (a). However, the watermark is still able to be extracted from the mixing images, as shown in Fig. 6 (b) and (d). Fig. 6 (c) is the extracted Cameraman image that is still well-marked. The test shows that the watermark will become perceptible when the additive noise energy level goes up some times lower than energy level of the watermark.

Finally, the damaging compression such as JPEG compression of the image is investigated. In general, compression can occur either before or after the image mixing. In Fig. 7, before we mix the original Lenna image, the key image and the watermark image, the mixtures are subject to JPEG compression. FICA are still able to blindly demix the host, the key and the mark images, as shown in Fig. 7 (d), (e) and (f) despite the transformation of the mixed images via JPEG compression.

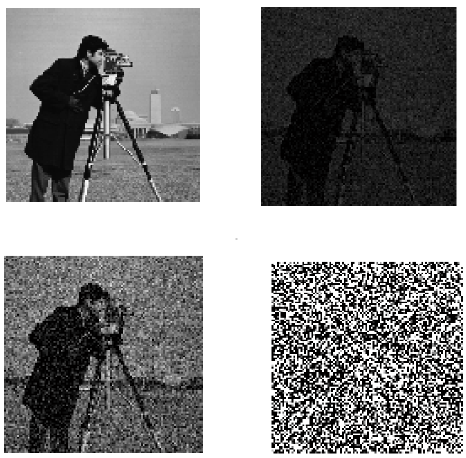
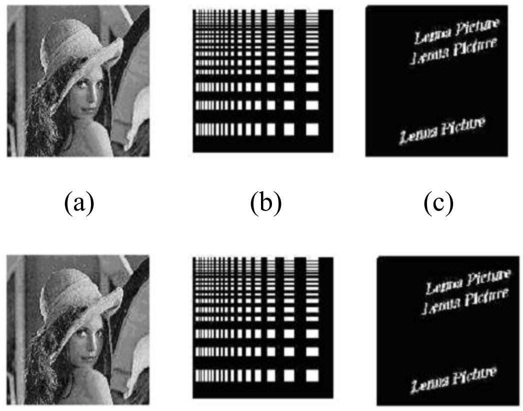


Fig. 6. Strong noise attacking simulation. (a) The original Cameraman image, (b) The watermarked Cameraman image with strong noise, (c) The extracted Cameraman image, (d) The extracted watermark of random sequence.



(a) (b) (c)

(d) (e) (f)

Fig. 7. Robustness of FICA demixing with respect to the JPEG image data compression. (a)-(c): The compressed original images. (d)-(f): The images demixed from compressed mixtures of originals.

6. CONCLUSIONS

This paper has briefly discussed the watermark system and the new method for digital image watermark processing using ICA. The method is based on a fast blind source separation algorithm. The experimental results have shown the validity and feasibility in applying ICA technique for performing digital image watermark detection and extraction. The watermark data are easily detected by PCA whitening processing. The watermark can be further separated from the mixed sources by using the FastICA algorithm. The performance analysis was carried by estimating the normalized correlation coefficient, which showed that the satisfied de-watermarking performance of the proposed approach can be obtained. The robustness test is also performed and evaluated. The experimental results demonstrate the validity and feasibility of the FastICA algorithm in the applications of digital image watermark processing.

ACKNOWLEDGEMENT:

This work was supported in part by the National Natural Science Foundation of China (60271023), the Key Grant of Natural Science Foundation of Guangdong, China (021264) and the Key Grant of the Education Ministry of China (02110).

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