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基于Tchebichef矩的几何攻击不变性第二代水印算法*

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Geometric Distortions Invariant Blind Second Generation Watermarking Technique Based on Tchebichef Moment of Original Image

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Abstract: In this approach, a rotation, scaling and translation invariant blind second generation watermarking technique is proposed using Tchebichef moments of the original image to estimate the geometric distortion parameters of the corrupted watermarked images. The Tchebichef moments of original image can be used as private key of watermark extraction process. The characteristics of the human visual system are incorporated into the watermark embedding, and the embedding process can be performed in any image domain, including spatial and transform domain. A method in DWT domain is proposed in this paper. Independent Component Analysis is adopted by watermark detector so that the watermark can be correctly extracted but not merely detected. The experimental results show that this method has a good robustness to attacks produced by the popular watermarking test software Stirmark.
Key words: geometric distortion; Tchebichef moment; second generation watermarking; independent component analysis

摘　要: 提出了一种基于原始图像的 Tchebichef 矩实现的几何攻击不变性第二代盲水印算法,利用原始图像的 Tchebichef 矩估计图像可能经历的几何攻击的参数来还原图像,其中,原始图像的 Tchebichef 矩可作为水印检测器的密钥.水印嵌入过程结合人类视觉系统的特性,且可在任何图像变换域中实现,给出了小波域的一种实现方法.水印检测过程采用独立分量分析技术不仅可以检测到水印而且可以提取水印,实现了真正意义上的盲检测.实验结果表明,该水印算法对于通用水印测试软件 Stirmark 提供的各种攻击具有很好的鲁棒性.
关键词: 几何攻击;Tchebichef 矩;第二代水印技术;独立分量分析
中图法分类号: TP309　　**文献标识码**: A

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1 Introduction

Digital watermarking technique[1] is an effective means to resolve these problems by embedding additional information (watermark information) into digital protected media. In order for a watermark to be useful, it must be perceptually invisible and have robustness against image manipulation, processing operations, and a variety of possible attacks by pirates. There has been much emphasis on the robustness of watermarking against common signal processing operations. However, recently it has become clear that even very small geometric distortions can prevent the detection of a watermark. This problem is most pronounced for blind detection, which host image is unavailable to the detector.

Kutter gave the first definition of the second generation watermarking[2], which involves the notion of perceptually significant features of the protected data. Taking the example of images, features can be edges, corners, textured areas or parts in the image with specific characteristics, and the edge of the original image extracted by Sobel operator is used as watermark in this paper.

Geometric attacks are common in watermarking technique, which do not actually remove the embedded watermark itself but intend to distort the watermark detector synchronization. Yet how to design watermarking techniques with robustness against geometric distortions is still an open issue. We assume that the detector is not informed any information of geometric distortions. There are some watermarking techniques using DCT[3], DWT[4], DFT and spatial domain[5], and they perform well against compression, but lack of robustness to geometric distortions. Some methods have been proved to be robust against geometric distortions proposed in DFT[6,7]. Since the wavelet coefficients of image are sensitive to the original orientation, it is hard for watermarking robust against geometric distortions in DWT. Masoud A[8] presented a solution to estimate scaling factor and rotation angle based on computing edges standard deviation ratio and average edges angle difference, assuming that detector has prior information regarding wavelet maxima of the original images.

Recently, blind source separation by Independent Component Analysis (ICA) has received attention because of its potential applications in signal processing. The goal of ICA is to recover independent sources when only sensor observations that are unknown linear mixtures of the unobserved independent source signals are given. The goal is to perform a linear transform, which makes the resulting variables as statistically independent from each other as possible. ICA is a fairly new and generic method in signal processing. It reveals a diversity of theoretical challenges and opens a variety of potential applications. Successful results in EEG, FMRI, speech recognition and face recognition systems indicate the power and optimistic hope in this new paradigm.

The main contribution of this paper lies in the proposal of a rotation, scaling and translation invariant second generation image watermarking in DWT domain, which only uses the Tchebichef moment of the original image to estimate the geometric distortion parameters of the corrupted watermarked image. This estimation method can be used as preprocess of watermark detection in order to restore synchronization of watermarking embedding and detecting process. We have done the work of estimating the geometric distortion parameters by using the geometric moments[9]. The watermark detector is based on ICA, which will extract the watermark, but not merely detect it without using the original watermark and image during the detection. It is a completely blind method during watermark detection. The method had gone through testing against all the attacks produced by the popular “Stirmark” attacks. Experimental results show that this method has a good robustness against geometric distortions produced by Stirmark.

2 Definition of Tchebichef Moments

It is known that if $\{t_n(x)\}$ is a set of discrete orthogonal polynomials with unit weight, satisfying the condition that:

$$\sum_{x=0}^{N-1} t_m(x)t_n(x)=\rho(n,N)\delta_{mn},\ 0\le m,n\le N-1 \tag{1}$$

then any bounded function $f(x,y)$,$0\le\{x,y\}\le N-1$, has the following polynomial representation in terms of the functions $t_n(x)$:

$$f(x,y)=\sum_{m=0}^{N-1}\sum_{N=0}^{N-1} T_{mn}t_m(x)t_n(y) \tag{2}$$

where the coefficient T_{pq} is given by:

$$T_{pq}=\frac{1}{\rho(p,N)\rho(q,N)}\sum_{x=0}^{N-1}\sum_{y=0}^{N-1} t_p(x)t_q(x)f(x,y)\ ,p,q=0,1,2,\ldots,N-1 \tag{3}$$

Eq.(3) is easily obtained by substituting for $f(x,y)$ using Eq.(2) in the expression $\sum_{x=0}^{N-1}\sum_{y=0}^{N-1} t_p(x)t_q(x)f(x,y)$ and noting that $\rho(p,N)$ is Tchebichef polynomials:

$$\rho(p,N)=\sum_{x=0}^{N-1}\{t_p(x)\}^2 \tag{4}$$

The simplest among orthogonal moment systems is the Tchebichef polynomial, which can be defined as Ref.[10] for square images of size $N\times N$ pixels:

$$T_{pq}=\frac{1}{\tilde{\rho}(p,N)\tilde{\rho}(q,N)}\sum_{x=0}^{N-1}\sum_{y=0}^{N-1}\tilde{t}_p(x)\tilde{t}_q(y)f(x,y) \tag{5}$$

where $f(x,y)$ is luminance function of the original image with size $N\times N$. $\tilde{t}_n(x)$ is defined as: $\tilde{t}_n(x)=\dfrac{t_n(x)}{\beta(n,N)}$.

$\beta(n,N)$ is a suitable constant which is independent of x and the simplest choice is $\beta(n,N)=N^n$. $t_n(x)$ is the discrete Tchebichef polynomial of degree n and can be defined as:

$$t_n(x)=(1-N)_n {}_3F_2(-n,-x,1+n;1,1-N;1),n,x,y=0,1,2,\ldots,N-1 \tag{6}$$

$(a)_k$ is the Pochhammer symbol given by $(a)_k=a(a+1)(a+2)\ldots(a+k-1)$. And ${}_3F_2(.)$ is the generalized hypergeometric function ${}_3F_2(a_1,a_2,a_3;b_1,b_2,z)=\sum_{k=0}^{\infty}\frac{(a_1)_k(a_2)_k(a_3)_k}{(b_1)_k(b_2)_k}\frac{z^k}{k!}$.

With the above definitions, Eq.(6) can also be written as:

$$t_n(x)=n!\sum_{k=0}^{n}(-1)^{n-k}\binom{N-1-k}{n-k}\binom{n+k}{n}\binom{x}{k} \tag{7}$$

The scaled Tchebichef polynomials satisfy the property of orthogonal and are defined as:

$$\tilde{\rho}(n,N)=\frac{\rho(n,N)}{\beta(n,N)^2}=\frac{N\left(1-\frac{1}{N^2}\right)\left(1-\frac{2^2}{N^2}\right)\ldots\left(1-\frac{n^2}{N^2}\right)}{2n+1}\ ,n=0,1,\ldots,N-1 \tag{8}$$

This equation also leads to the following inverse moment transform:

$$f(x,y)=\sum_{m=0}^{N-1}\sum_{n=0}^{N-1}T_{mn}\tilde{t}_m(x)\tilde{t}_n(y)\ ,x,y=0,1,\ldots,N-1 \tag{9}$$

Since only square images have Tchebichef moments, the image must be mended as square image if it is not square, and the moment of the mended image will be used during the estimation.

3 Methodology of Estimating Geometric Distortion Parameters

In this section, how to estimate geometric distortion parameters of a previously corrupted watermarked image will be described in detail by only using one or two Tchebichef moments of the original image. The methodology of estimating the single geometric distortion parameter is described in detail. By this way, the parameters can also be estimated when the watermarked image encountered several attacks with one or two more Tchebichef moments of the original image will be needed.

3.1 Rotation angle estimation

The rotation operator performs a geometric transform, which maps the position of a picture element in an input image onto a position in the corresponding output image by rotating it through a user-specified angle θ about an original.

Define $f(x',y')$ as the watermarked image rotated by θ degree, that is, the pixel (x',y') is obtained by rotating the pixel (x,y) by θ degree. Assume that the watermarked image is rotated by the center normalized as (0,0), we can get that:

$$\begin{cases} x' = r\cos(\theta+\alpha) = r\left(\cos\theta\dfrac{x}{r} - \sin\theta\dfrac{y}{r}\right) = x\cos\theta - y\sin\theta \\ y' = r\sin(\theta+\alpha) = r\left(\sin\theta\dfrac{x}{r} + \cos\theta\dfrac{y}{r}\right) = x\sin\theta + y\cos\theta \end{cases} \tag{10}$$

So we can get that:

$$T'_{10}\cos\theta + T'_{01}\sin\theta = T_{10} + \frac{3(1-N)N^2}{N(N^2-1)}(\cos\theta+\sin\theta-1)T_{00} \tag{11}$$

where T_{00}, T_{10} are the Tchebichef moments of the original image. T'_{10} and T'_{01} are the Tchebichef moment of the rotated watermarked image. Only two Tchebichef moments of the original image are used during the estimation θ, which can be computed by numerical analysis. Suppose that:

$$\Delta = T'_{10}\cos\theta + T'_{01}\sin\theta - T_{10} - \frac{3(1-N)N^2}{N(N^2-1)}(\cos\theta+\sin\theta-1)T_{00}.$$

Once θ satisfies $\Delta<\varepsilon$, we will get the estimated result. Where ε is a positive value that is small enough and we set $\varepsilon=10^{-5}$ in our experiments.

3.2 Scaling factor estimation

The scale operator performs a geometric transformation, which can be used to shrink or zoom the size of an image (or part of an image). Scaling can be divided into two categories: one is symmetric scaling, which means that the scaling factor in the direction is the same as that in the direction, and the other is asymmetric scaling sometimes called as shearing, which means that the scaling factors are different in two directions. Since only the square images have Tchebichef moment, only symmetric scaling is concerned here. Suppose $f\left(\dfrac{x}{a},\dfrac{y}{a}\right)$ is the scaled watermarked image of the original image $f(x,y)$, that is, scaling factor in x and y directions is a. So we can get the Tchebichef moments of the original image and the scaled watermarked image as:

$$T_{00} = \frac{\sum_{x=0}^{N-1}\sum_{y=0}^{N-1} f(x,y)}{N^2},\ T'_{00} = \frac{\sum_{x'=0}^{N'-1}\sum_{y'=0}^{N'-1} f(x',y')}{N'^2} \tag{12}$$

So we can estimate the scaling factor by:

$$a=\sqrt{\frac{N'^2T'_{00}}{N^2T_{00}}} \tag{13}$$

where T_{00} and T_{10} are the Tchebichef moments of the original image. T'_{10}, T'_{01} and T'_{00} are the Tchebichef moments of the scaled watermarked image. The original image size is $N\times N$ and the scaled watermarked image size is $N'\times N'$.

3.3 Translation parameter estimation

Since the discrete wavelet coefficients of images are sensitive to position, it is very important for a robust watermarking with respect to translation in DWT domain. Suppose T_{10} and T_{01} are the Tchebichef moments of the original image, T'_{10} and T'_{01} are the Tchebichef moments of the translated watermarked image. So we can get the translation parameters from:

$$\begin{cases} x'=x+c \\ y'=y+d \end{cases} \tag{14}$$

where c and d are the translation parameters in x and y directions respectively. So we can get the Tchebichef moments of the original image as:

$$T_{10}=\frac{6\sum_{x=0}^{N-1}\sum_{y=0}^{N-1}xf(x,y)+3(1-N)\sum_{x=0}^{N-1}\sum_{y=0}^{N-1}f(x,y)}{N(N^2-1)},\ T_{01}=\frac{6\sum_{x=0}^{N-1}\sum_{y=0}^{N-1}yf(x,y)+3(1-N)\sum_{x=0}^{N-1}\sum_{y=0}^{N-1}f(x,y)}{N(N^2-1)} \tag{15}$$

And the Tchebichef moments of the translated watermarked image

$$T'_{10}=\frac{6\sum_{x=0}^{N-1}\sum_{y=0}^{N-1}(x+c)f(x,y)+3(1-N)\sum_{x=0}^{N-1}\sum_{y=0}^{N-1}f(x,y)}{N(N^2-1)},\ T'_{01}=\frac{6\sum_{x=0}^{N-1}\sum_{y=0}^{N-1}(y+d)f(x,y)+3(1-N)\sum_{x=0}^{N-1}\sum_{y=0}^{N-1}f(x,y)}{N(N^2-1)} \tag{16}$$

So we can deduce that:

$$T'_{10}=\frac{6\sum_{x=0}^{N-1}\sum_{y=0}^{N-1}xf(x,y)+3(1-N)\sum_{x=0}^{N-1}\sum_{y=0}^{N-1}f(x,y)}{N(N^2-1)}+\frac{6\sum_{x=0}^{N-1}\sum_{y=0}^{N-1}cf(x,y)}{N(N^2-1)}=T_{10}+\frac{6cNT_{00}}{N^2-1} \tag{17a}$$

$$T'_{01}=\frac{6\sum_{x=0}^{N-1}\sum_{y=0}^{N-1}yf(x,y)+3(1-N)\sum_{x=0}^{N-1}\sum_{y=0}^{N-1}f(x,y)}{N(N^2-1)}+\frac{6\sum_{x=0}^{N-1}\sum_{y=0}^{N-1}df(x,y)}{N(N^2-1)}=T_{01}+\frac{6dNT_{00}}{N^2-1} \tag{17b}$$

From Eq.(17) we can estimate the translation parameters c and d by the Tchebichef moments:

$$c=(N^2-1)(T'_{10}-T_{10})/(6NT_{00}),\ d=(N^2-1)(T'_{01}-T_{01})/(6NT_{00}) \tag{18}$$

4 Methodology of the Second Generation Watermarking Process

In this section, we will describe the second generation watermarking technique, which is robust with respect to the geometric distortions in detail.

4.1 Watermark embedding process

The second generation watermarking system can be realized in any image domain. In this paper, the watermark is embedded in DWT domain, and 4 levels of DWT are conducted to the original image. The watermark can also be embedded in DCT, DFT and spatial domain with different watermark embedding intensity. The watermark embedding intensity in different wavelet transform levels is determined by just noticeable difference of human visual system in DWT domain[11]. The embedding steps are described as follows:

Step 1. Watermark creation and preprocess. The edge of the original image is used as watermark expressed by W, which is extracted by Sobel operator. It is beneficial to preprocess the watermark before embedding to enhance the security of the watermark. In this paper the preprocess is to rearrange the watermark by Cat map, which can be expressed as:

$$\begin{pmatrix} x_{n+1} \\ y_{n+1} \end{pmatrix} = \begin{pmatrix} 1 & 1 \\ 1 & 2 \end{pmatrix} \begin{pmatrix} x_n \\ y_n \end{pmatrix} (\mathrm{mod}\ 1) \tag{19}$$

Cat map parameters can be used as a private key during the watermark detection process.

Step 2. Watermark embedding process. Both original and watermark images are decomposed into 4 levels using DWT. The approximation components ($LL1$,$LL2$,$LL3$,$LL4$) in each level are not chosen because any change on the approximation details will seriously degrade the image quality. The other components of the watermark are added to the host image. Let the original vector of the host image be X, the embedding strength be α, and the watermarked image be Y. The watermark embedding process can be expressed as:

$$Y(k,i,j)=X(k,i,j)+\alpha(k,i)W(k,i,j) \tag{20}$$

where, k=level of decomposition, k=1,2,3,4. i=decomposition component, and i=1,2,3 indicates HL/LH/HH respectively. j=index of embedding coefficient in component i.

Step 3. Perform the inverse DWT (IDWT) to retrieve the watermarked image.

4.2 Watermark detection process

ICA process is the core of the proposed watermark detector accomplished by the FASTICA algorithm[12]. Assume that n observed linear mixtures $x_1,\ldots,x_n$ of n independent components can be expressed as:

$$x_j=a_{j1}s_1+a_{j2}s_2+\ldots+a_{jn}s_n \text{ for all } j=1,\ldots,n \tag{21}$$

Without loss of generality, both the mixture variables and the independent components can be assumed to have zero mean. We have:

$$X=AS \tag{22}$$

where X is the observed vector, S is the original source vector and A being the mixed matrix, and both S and A are unknown. The statistical model expressed in Eq.(22) is called independent component analysis, or the ICA model. X represents all the observed data, and both A and S must be estimated from it. If we know the separate matrix L, we can estimate the source signal easily. That is, we can estimate the source by:

$$S=LX \tag{23}$$

So it is important to compute the correct separate matrix during the independent components analysis process. Before applying the ICA model, it is helpful to conduct preprocessing such as centering and whitening to simplify the ICA process. We can use a private key to extract the watermark after performing the ICA to the preprocessed watermarked image. The process of watermark detector is described in detail as follows:

Step 1. Preprocessing of the test image for centering and whitening. The observed variable x is centered by subtracting the mean vector $m=E\{x\}$ from the observed variable, this makes x a zero-mean variable. This preprocessing is designed to simplify the ICA algorithms. After estimating the mixing matrix A with the centered data, we can complete the estimation by adding the mean vector of the original source signal back to the centered estimates of the source data**.** Another preprocessing is to whiten the observed variables. Whitening means to transform the variable x linearly so that the new variable $\tilde{x}$ is white, i.e., its components are uncorrelated, and their variances equal unity. In other words, variable $\tilde{x}$ is white means the covariance matrix of $\tilde{x}$ equals to the identity matrix: $E\{\tilde{x}\tilde{x}^T\}=I$ that is, $\tilde{x}$ is uncorrelated. Whitening can be computed by eigenvalue decomposition of the covariance matrix:

$$E\{xx^T\}=EDE^T \tag{24}$$

where, E is the orthogonal matrix of eigenvector of $E\{xx^T\}$. D is a diagonal matrix of its eigenvalues, that is $D=diag(d_1,\ldots,d_n)$. Note that $E\{xx^T\}$ can be estimated from $x(1),\ldots,x(n)$.

Step 2. Perform ICA to the signal that has been centered and whitened, that is to find the separate matrix L:

1. Choose an initial (e.g., random) weight vector L; Let $L^+=E\{yG(L^Ty)\}-E\{G'(L^Ty)\}L, L=L^+/||L^+||$, where, $E(\bullet)$ is the mean computing factor. $G(\bullet)$ is a non-linear function and the following choices of $G(\bullet)$ have proved to be very useful: $G_1(u)=tanh(a_1u)$, $G_2(u)=uexp(-u^2/2)$.
2. If the difference between the iterative results is less than the threshold, that is, $|L^+-L|<\varepsilon$ we can say that the process is converged and the cycle will terminate; otherwise, go back to Step 2 until the result is converged. The threshold ε can be defined by user and we use $\varepsilon=10^{-6}$ in our experiments. If the result is still not converged after 3 000 cycles, then the process will be forced to terminate and we can conclude that there is no independent component for the corrupted watermarked image.

If there are multiple watermarks in the tested image, the extracted watermark must be subtracted before extracting the next one.

Step 3. Extract the perfect watermark by using the key in the watermark embedding process.

5 Computational Complexity Analysis

The basis functions of Tchebichef moments are orthogonal in the domain of the image coordinate space, and this feature completely eliminates the need for any discrete approximation in their numerical implementation.

The symmetry property can be used to considerably reduce in time required for computing the Tchebichef moments. The scaled Tchebichef polynomials have the same symmetry property which the classical Tchebichef polynomials satisfy:

$$\tilde{t}_n(N-1-x)=(-1)^n\tilde{t}_n(x) \tag{25}$$

This relation suggests the subdivision of the domain of an $N\times N$ image (when N is even) into four equal parts, and performing the computation of the polynomials only in the first quadrant where $0\le x,y\le\left(\frac{N}{2}-1\right)$.

On the other hand, the Tchebichef moments can be written in terms of the geometric moments. If $p+q$ order geometric moments of an image $f(x,y)$ are expressed using the discrete sum approximation as:

$$m_{pq}=\sum_{x=0}^{N-1}\sum_{y=0}^{N-1}x^py^qf(x,y) \tag{26}$$

Then the Tchebichef moments of the same image may be expressed in terms of geometric moments as follows:

$$T_{pq}=A_pA_q\sum_{k=0}^{p}C_k(p,N)\sum_{l=0}^{q}C_l(q,N)\times\sum_{i=0}^{k}\sum_{j=0}^{l}s_k^{(i)}s_l^{(j)}m_{ij} \tag{27}$$

where $A_p=\frac{1}{\beta(p,N)\tilde{\rho}(p,N)}$, $C_k(n,N)=(-1)^{n-k}\frac{n!}{k!}\binom{n-1-k}{n-k}\binom{n+k}{n}$, $\frac{x!}{(x-k)!}=\sum_{i=0}^{k}s_k^{(i)}x^i$. It is seen that the Tchebichef moments depend on the geometric moments up to the same order. The explicit expression of the Tchebichef moments in terms of geometric moments (for $\beta(n,N)=N^n$) are as follows:

$$T_{00}=\frac{m_{00}}{N^2},\ T_{10}=\frac{6m_{10}+3(1-N)m_{00}}{N(N^2-1)},\ T_{01}=\frac{6m_{01}+3(1-N)m_{00}}{N(N^2-1)} \tag{28}$$

The matrix form of representation is very useful, especially for fast computation and implementation in MATLAB. In matrix form the Tchebichef moment can be computed using:

$$T=CIC^T \tag{29}$$

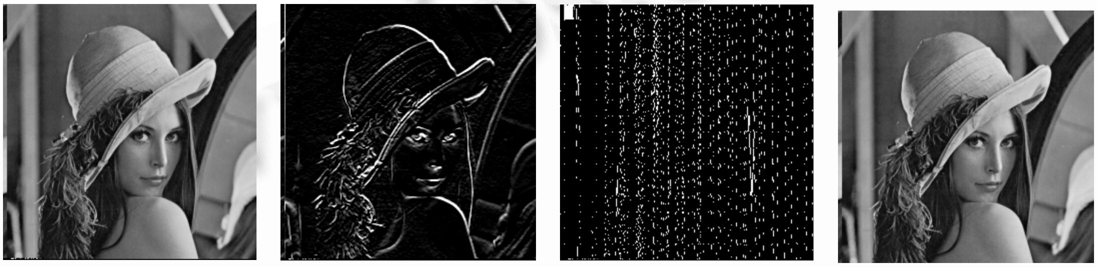
where T is the moment matrix, $T=\{T_{i,j}\}_{i,j=0}^{N-1,N-1}$. I is the image matrix, $I=\{f(i,j)\}_{i,j=0}^{N-1,N-1}$. C is the Tchebichef polynomial matrix, $C=\{t_{i,j}\}_{i,j=0}^{N-1,N-1}$. The inverse moment transform is

$$T=C^TIC \tag{30}$$

Set $\beta(n.N)=\rho(n,N)$ to further simplify the computation. The direct calculation of a two-dimensional Tchebichef moments of order up to T^{th} from Eq.(5) requires $\frac{1}{6}N(T+2)(T+1)(4T+3N-9)$ multiplications and $\frac{1}{6}(T+2)(T+1)(2NT+3N^2-6N-9)$ additions. We know that the term $\tilde{\rho}(n,N)$ needs only to be calculated at most once per moment. So for Tchebichef moment of order up to T^{th}, the calculation will requires $\frac{1}{24}(T+2)(T+1)(T^2+7T+24)$ multiplications and $\frac{1}{3}T^3+T^2+\frac{2}{3}T$ additions.

6 Simulation Results

All the attacks are produced Stirmark, which is popularly used to test watermarking technique. The edge of the original image is used as watermark, which extracted by Sobel operator. The watermark is rearranged before watermarking embedding. Experimental results showed that this watermark technique have good robustness against Stirmark. The original image, watermark and watermarked image are showed in Fig.1.



(a) Original image (b) Extracted edge (watermark) (c) Rearranged watermark (d) Watermarked image

Fig.1

Normalization Correction (NC) is used to express the similarity between the original watermark w and the extracted watermark w^* quantitatively and use the Peak Signal to Noise Ratio (PSNR) to express the difference between the watermarked image $y_{i,j}$ and the original image $x_{i,j}$. It is observed that the higher NC, the more similarity between the extracted watermark and the original watermark. The definitions of the NC and PSNR are given below[15]:

$$PSNR=10\log\left(x_{\max}^2/\left(N^{-2}\sum_{i=1}^{N}\sum_{j=1}^{N}(x_{i,j}-y_{i,j})^2\right)\right) \tag{31}$$

$$NC=\frac{\sum_{i=0}^{255}\sum_{j=0}^{255}w(i,j)w^*(i,j)}{\sum_{i=0}^{255}\sum_{j=0}^{255}(w(i,j))^2} \tag{32}$$

6.1 Experimental results with rotation angle estimation

The estimation results are listed in Table 1 with unit as degree and compared to Ref.[8]. From the results we can see that rotation angle can be estimated with a high precision even with a large angle. "−" means no results in Ref.[8].

6.2 Experimental results with scaling factor estimation

We do the scaling factor estimation experiment and Table 2 lists the estimation results compared to those given in Ref.[8]. From the results we can see that the estimation results of scaling factor have a high precision.

Table 1 Rotation angle estimation compared to Ref.[8]

Factual	Estimate angle	Results in Ref.[8]	Factual	Estimate angle	Results in Ref.[8]
0.1	0.09999999999404818	—	0.2	0.1999999999940482	—
0.3	0.2999999999940482	—	0.4	0.3999999999940482	—
−0.5	−0.5000000000059518	−0.5068	−1	−1.000000000005952	−0.89
−2	−2.000000000005953	−1.88	5	4.999999999994047	—
−10	−10.00000000000593	—	30	29.99999999999421	—
45	43.99999999999440	—	60	59.99999999999463	—
90	89.99999999999321	—	−180	−179.99999999998	—

Table 2 Scaling factor estimation scaled by Stirmark compared to Ref.[8]

Factual	Estimate data	Results in Ref.[8]	Factual	Estimate data	Results in Ref.[8]
0.5	0.49907	0.4715	0.75	0.74957	0.7445
1.25	1.24984	—	1.5	1.499699	1.4831
2	1.99935	1.9482	2.5	2.49905	—
4	3.998064	—	0.25	0.24718	—

6.3 Experimental results with translation parameters estimation

We do translation parameters estimation and Table 3 lists the estimation results. From the results we can see that the estimation results of translation factor have a high precision.

Table 3 Translation parameters estimation translated by Stirmark

X factual	*Y* factual	Estimate *x*	Estimate *y*	*X* factual	*Y* factual	Estimate *x*	Estimate *y*
1	1	1.000000000000291	1.000000000000214	1	2	1.000000000000291	2.000000000000157
2	2	2.000000000000505	2.000000000000157	3	3	3.000000000000564	3.000000000000410
3	5	3.000000000000564	5.000000000000837	5	5	5.000000000000258	5.000000000000837
5	10	5.000000000000258	10.00000000000133	10	10	10.00000000000156	10.00000000000133
10	20	10.00000000000156	20.00000000000192	30	30	30.00000000000348	30.00000000000282

6.4 Experimental results with rotation angle and scaling factor combined estimation

No matter what order of geometric distortions of rotation and scaling done to the watermarked images, we estimate the geometric distortion parameters in the same way and Table 4 gives the estimation results. During the experiments, we find that even different watermarks embedded in different image transform domains, the results are nearly the same and the estimation results have a high precision.

Table 4 Rotation angle and scaling factor estimation in different domains

Angle	*X* factor	*Y* factor	Estimation angle	Estimate *x* factor	Estimate *y* factor
2	0.5	0.5	2.0000000000004	0.49874	0.49874
2	1.5	1.5	2.0000000000004	1.50126	1.50126
2	2.0	2.0	2.0000000000004	2.00251	2.00251
2	1.25	1.5	2.0000000000004	1.25083	1.50099
−1	0.5	0.5	−0.99999999998	0.49874	0.49875
−1	1.5	1.5	−0.99999999998	1.50126	1.50126
−1	2.0	2.0	−0.99999999998	2.00251	2.00251
−1	1.25	1.5	−0.99999999998	1.25084	1.50101

6.5 Experimental results with translation parameter and scaling factor estimation

No matter what order of geometric distortions of translation and scaling is done to the watermarked image, we estimate the translation parameter and scaling factor with Tchebichef moments of the original image. Table 5 gives the estimation results of translation and scaling estimation results. The attacks are given by Stirmark and the estimation results have a high precision.

Table 5 Translation parameter and scaling factor estimated by Stirmark

Angle	*X* translation	*Y* translation	Estimate angle	*X* estimate translation	*Y* estimate translation
0.5	1	2	0.49873421718931	1.00033996714081	1.9996978134468
0.5	10	20	0.4895492807075	10.2701028302855	17.428690097641
0.75	5	5	0.74909936257870	4.98902672081308	4.9941205597733
1.25	3	3	1.2506689651710	3.00132235690239	3.0008159925905
1.25	15	15	1.25066896517105	15.00132235690322	15.00081599259033
1.5	5	5	1.5013265776978	4.99802735395248	5.0017634328579
1.5	10	20	1.5013265776978	9.99802735395312	20.001763432857
2.00	1	2	2.0025062735009	1.00000024777553	1.9999998954528
2.00	15	15	2.00250627350094	15.00000024777901	14.99999989545282

6.6 Experimental results with robust against JPEG compression

Experiments are performed to examine the robustness of the proposed intelligent watermark detection to the JPEG compression produced by Stirmark with different qualified factors Q and Table 6 lists the results.

Table 6 Robust to JPEG compression produced by Stirmark

Qualify factor	90	80	70	60	50	40	30	20	10
PSNR	72.8911	42.9237	41.4464	38.3789	36.9986	35.3863	34.1631	32.3656	29.4666
NC	0.9935	0.9929	0.9926	0.9911	0.9897	0.9803	0.9460	0.9303	0.8445

6.7 Experimental results with other Stirmark attacks

We also do experiments to other kinds of attacks by Stirmark to test the robustness of the proposed blind second generation watermark technique. Table 7 lists some experimental results by the Stirmark attacks.

Table 7 Experimental results to Stirmark

Attack	Remove one row one column	Median filter	Convolution filter	Skew x 5.0% y 5.0%	Rotation 2.00 degree with scaling 2.0 with crop
NC	0.9967	0.9989	0.9237	0.9977	0.7825

6.8 Experimental results comparisons

We compare our results with those of Ref.[14]. The authors adopted the ICA in spatial domain. Figure 2 shows the comparisons on the attacks of scaling and rotation.

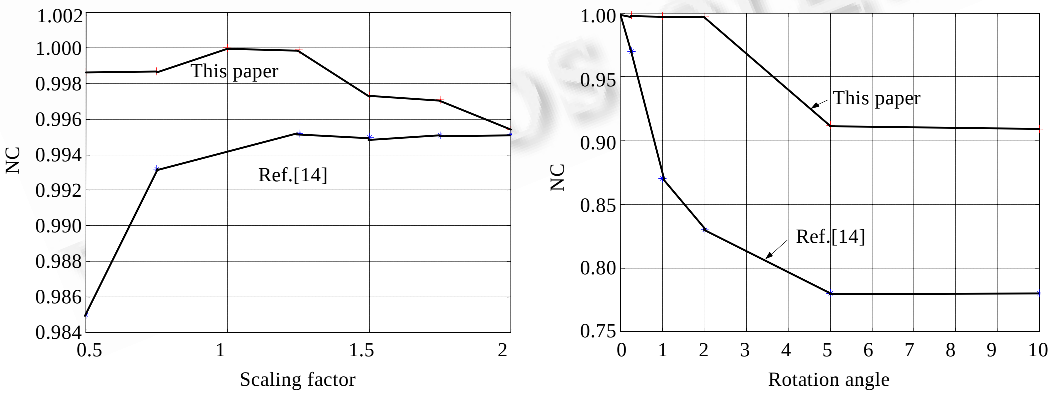


Fig.2 NC comparison (scaling and rotation)

We compare the experimental results of the method proposed in this paper to those of Ref.[7], which proposed a digital watermarking technique in DFT domain and some commercial watermark techniques and Table 8 shows the results. The method proposed in this paper can be realized in any domain, including DWT, DCT, DFT and spatial domain.

Table 8 Experimental results compared to Ref.[7] and two commercial watermark techniques

Attack	Results in Ref.[7]	Digimarc technique	Suresign technique	The method proposed this paper
Scaling	0.78	0.72	0.95	1
Rotation	1	0.94	0.5	1
Flipping	1	—	—	1
Translation	Not done	—	—	1
Random geometric distortion	0	0.33	0	1
Cropping	0.89	—	—	0.95
JPEG compression	0.74	0.81	0.95	0.91

7 Conclusions

We present a geometric distortion invariant second generation blind image watermarking technique in DWT domain, which estimates the geometric distortion parameters for a corrupted watermarked image by using Tchebichef moments of the original image. The Tchebichef moments of the original can be used as the private key of watermark extraction process. If the watermarked image has been scaled, rotated and translated, the hidden information will be out of synchronization, then this may cause that the decoder cannot detect the watermark correctly. If we can estimate the geometric distortion parameters with a high precision, we can restore the corrupted watermarked image back to its original size and original orientation, and the decoder can detect the watermark normally. We assume that the detector is not informed any information of geometric distortions. The watermark is the edge of the original image extracted from the original image, and the characteristics of HVS are incorporated into the watermark embedding. The watermark is rearranged randomly before embedding in order to enhance the robustness, and the embedding process can be performed in any image domain. We propose a method in DWT domain. ICA is adopted by the watermark detector, which can extract the embedded watermarks, but not merely detect them. In our approach, we describe how to estimate the parameters of geometric distortions combined to the watermarked image by Stirmark benchmark. Experimental results show that this geometric distortion invariant second generation blind watermarking has a good robustness to popular watermark test software—Stirmark.

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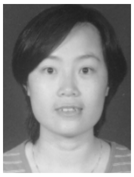

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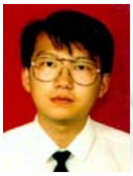

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