A Robust Watermarking Technique for Copyright protection of digital images

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Abstract: - Digital watermarking technique mainly applied protection in intellectual property copyrights. It is to join the data of the one intellectual property rights into the digital media of the different pattern by some procedures of processing. This includes text file, the static state image, the dynamic state image, voice signal, and so on. This paper proposes a robust watermark system that utilizes good geometry invariant characteristic of Zernike moment and Comparison of the average energy of wavelet packet. The experiments prove that the method is robust against scaled, rotated, blurred, cut and jpeg attacks. Particularly, the use of the Zernike moment improves the robustness against geometric attacks greatly.

Keywords: watermarking, wavelet packet, Zernike moment

1 Introduction

Digital watermarking is a technique for embedding a watermark into a digital image to protect the owner's copyright of the image. Many watermarking techniques have been proposed in recent years.[7]-[16] Digital watermark strategies fall into two major categories: spatial-domain and transform-domain techniques. To avoid distortion of the image quality and increase the survival of watermark, there are many requirements for a well-designed watermark.

In this paper, we propose a novel robust watermarking method that uses the Zernike moment and wavelet packet .The experiments prove that the method is robust against scaled, rotated, blurred, cut and jpeg attacks. Particularly, the use of the Zernike moment improves the robustness against geometric attacks greatly. The remainder of this paper is organized as follows. In Section 2, Zernike moment and wavelet packet are introduced. In Section 3, the embedding and extraction processes of the watermark are described. In Section 4, the experimental results are given. Finally in Section 5, a summary will be made.

2 Zernike moment and wavelet packet

2.1 Zernike moment

Teague[4] has proposed the use of orthogonal moments to recover the image from moments based on the theory of orthogonal polynomials, and has introduced Zernike moments, which allow independent moment invariants to be constructed to an arbitrarily high order. The complex Zernike moments are derived from Zernike polynomials:

$$V_{nm}(x,y) = V_{nm}(\rho,\theta) = R_{nm}(\rho)\exp(jm\theta) \qquad (1)$$

and

$$R_{nm}(\rho) = \sum_{s=0}^{(n-|m|)/2} (-1)^s \frac{(n-s)!}{s!(\frac{n+|m|}{2}-s)!(\frac{n-|m|}{2}-s)!}\rho^{n-2s} \qquad (2)$$

Where n and m are subject to n-$|m|$ = even, $|m|<=n$. Zernike polynomials are a complete set of complex-valued function orthogonal over the unit disk, i.e., $x^2 + y^2 = 1$. Then the complex Zernike moments of order n with repetition m are defined as:

$$A_{nm} = \frac{n+1}{\pi}\sum_x\sum_y f(x,y)V^*_{nm}(x,y), x^2+y^2 \le 1 \qquad (3)$$

2.2 Rotation Invariance of Zernike Moment

Consider a rotation of the image through angle ϕ . If the rotated image is denoted by $f^r(\rho,\theta)$, the relationship between the original and rotated images in the same polar coordinate is

$$f^r(\rho,\theta) = f(\rho,\theta-\phi) \qquad (4)$$

It can be shown that the Zernike moments of the rotated image become [5] [6]

$$A_{nm}^r = \frac{n+1}{\pi}\int_0^{2\pi}\int_0^1 f(\rho,\theta-\phi)R_{nm}(\rho)\exp(-jm\theta)\rho d\rho d\theta \quad (5)$$

Set $\theta_1 = \theta - \phi$

$$A_{nm}^r = \frac{n+1}{\pi}\int_0^{2\pi}\int_0^1 f(\rho,\theta_1)R_{nm}(\rho)\exp(-jm(\theta_1+\phi))\rho d\rho d\theta_1$$

$$=[\frac{n+1}{\pi}\int_0^{2\pi}\int_0^1 f(\rho,\theta-\phi)R_{nm}(\rho)\exp(-jm\theta_1)\rho d\rho d\theta_1 \exp(-jm\phi)$$

$$= A_{nm}\exp(-jm\phi) \quad (6)$$

Equation (6) shows that each Zernike moment acquires a phase shift on rotation. Thus, the magnitude of the Zernike moment can be used as a rotation-invariant feature of the image.

2.3 Scale and translation invariance of Zernike Moment

Scale and translation invariance can be achieved by utilizing the image normalization technique as shown in [5], [6]. An image function can be normalized with respect to scale and translation by transforming it into, where

$$g(x,y) = f(\frac{x}{a}+\bar{x}, \frac{y}{a}+\bar{y})$$

with $(\bar{x}, \bar{y})$ being the centroid of f(x,y) and

$a=\sqrt{\beta / m_{00}}$,with β a predetermined value and m_{00} its zero-order moment. Hence, we first move the origin of the image into the centroid and scale it to a standard size. If we compute the Zernike moments of the image, then the magnitudes of the moments are RST invariant.

2.4 Rotation and scaling detection with Zernike moment

2.4.1 Rotation detection with Zernike moment

Consider a rotation of an image in the amount of ϕ , if the rotated image is denoted by f^r, the relationship between the original image and the rotated in polar coordination is

$$f^r(\rho,\theta) = f(\rho,\theta-\phi)$$

$$A_{nm}^r == A_{nm}\exp(-jm\phi)$$

If $m=0$, $A_{nm}^r = A_{nm}$, there is no phase difference between them. If $m\neq 0$, according to equation (6), we can have:

$$\arg(A_{nm}^r) = \arg(A_{nm}) + m\phi \quad (7)$$

$$\phi = \frac{\arg(A_{nm}^r) - \arg(A_{nm})}{m} \quad (8)$$

if an image has been rotated, we can compute the rotation degree ϕ by equation (8). For example, we can usually let *m=1, n=1.*, the rotation degree ϕ can be figured out.

2.42 Scaling detection with Zernike moment

Let f(x/a, y/a) represent a scaled version of the image function f(x, y). Then, the Zernike moment A_{00} of f(x, y) and A_{00}' of f(x/a, y/a), are related by [6]:

$$|A'_{00}| = \alpha^2 |A_{00}| \quad (9)$$

$$\alpha = \sqrt{\frac{|A'_{00}|}{|A_{00}|}} \quad (10)$$

the scaled rate α can be figured out.

2.5 Wavelet packet analysis

Discrete wavelet transforms, such as the Mallat[17] algorithm, based on orthogonal wavelets, have been widely used in image analysis. Wavelet transform hierarchically decomposes an input image into a series of successively lower resolution approximation images and their associated detail images. Two-dimensional one-level discrete wavelet transform (DWT) can be described in terms of filter banks as shown in figure 1. Two–dimensional DWT produces a decomposition of approximation coefficients (LL) and details in three orientations: horizontal (LH), vertical (HL) and diagonal (HH).

Wavelet packet trees are arbitrary sub-band decomposition trees, which represent generalisations of the wavelet tree. Compared with the discrete wavelet transform as figure2, wavelet packet decomposition can be flexibly designed for the given specific time-frequency filter. The main advantage of wavelet packet analysis over the Mallat wavelet decomposition is that not only can low-frequency signals be detected, but also the signals in the high-frequency band can be decomposed. Figure 3 shows the full-decomposed wavelet packet analysis

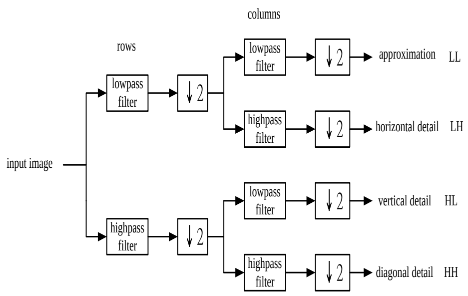


Figure1 Two-dimensional one-level discrete wavelet transform (DWT) described in terms of filter banks

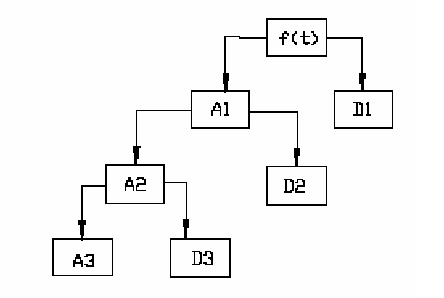


Figure 2 discrete wavelet transform analysis

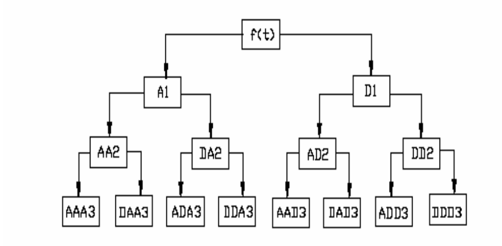


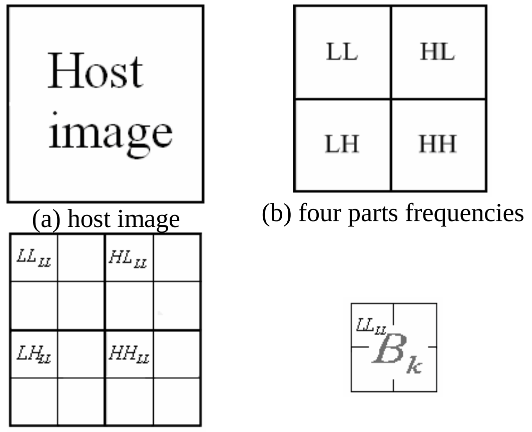
Figure 3 the full-decomposed wavelet packet analysis

3. THE ALGORITHM

3.1 Embedding the watermark

First, let $f(x,y)$ be the original grey-level host image. It is transformed into a binary digital image. Compute the Zernike Moment of the binary digital image. The values of A_{00} and A_{11} will be recorded and be used as the rotation and scaling detection.

$W(i,j)$ is the binary digital watermark of size WR×WC. In order to scramble the watermark, the pixels of the watermark will be permuted again randomly, and its random seed will be recorded. Thus, the watermark could be reset to its original state from the random seed.



(a) host image (b) four parts frequencies (c) sixteen sub-bands (d) sub-block

Figure.4 Full-decomposed wavelet packet

The procedure of embedding is described as follows:

Step1. Divide the host image into many non-overlapping blocks. Each block is decomposed into completely 2nd-level discrete wavelet transform (i.e. DWT) by full-decomposed wavelet packet, as mentioned previously. Which means if we decompose every non-overlapping block by 1st-level DWT, it is changed into four parts of high, middle, and low frequencies (i.e. LL, HL, LH, and HH bands), as show in figure 4.(a) and 4.(b).

Step2. To analyses LL, HL, LH, and HH in all of the non-overlapping blocks by 1st-level DWT. Therefore, every block is decomposed into sixteen sub-bands, which are classified four non-overlapping sub-blocks, denoted as B_k , and shown in figure 4.(c) and 4.(d), k=0, 1,2…K-1. That is

$$f(x,y) = \bigcup_{k=0}^{K-1} B_k \quad , \; K = \frac{M}{WR} \times \frac{N}{WC} \qquad (11)$$

In order to allow the number of non-overlapping sub-blocks K be the same as the size of watermark WR×WC, we can calculate the number K by equation (12).

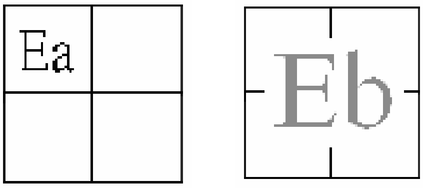
$$\left(\frac{M}{WR} \times \frac{N}{WC}\right) \cdot (2 \times 2) = \left(\frac{M}{WR} \cdot 2\right) \times \left(\frac{N}{WC} \cdot 2\right) \quad (12)$$

For example, let the grey-level image of size 512×512 be the original host image. And W will be the binary digital watermark of size 64×64. The original image $f(x,y)$ is segmented into 32×32 non-overlapping blocks with size16×16, by equation (12). Decompose each block by 1st-level DWT, we will find four parts of frequencies, LL, HL, LH, and HH, as show in figure

4.(b). Then analyses the four parts of frequencies of block by 1st-level DWT again, into to sixteen sub-bands, as show in figure 4.(c). The sub-bands with number 2×2 will be classified to a sub-block B_k, as show in figure 4.(d), and the number of K can be computed by equation(11).

Step3. Calculate the average energy Ea of the low frequency in the sub-block by equation (13) and show as in figure 5.(a). Where E is the average energy, P and Q are the width and height of the bands, $y(p,q)$ represents the wavelet coefficient of DWT. And regard Ea as a threshold value.

$$E = \frac{1}{PQ} \sum_{p=1}^{P} \sum_{q=1}^{Q} y^2(p,q) \qquad (13)$$



(a) (b)

Figure.5 (a) mean energy of LL sub-band
(b) mean energy of the whole sub-block

For instance, we compute the average energy of the LL_{LL} sub-band in the sub-block, as show in figure 4.(c), and denote it as Ea. And then count Ea of other low frequencies such as HL_{LL}, LH_{LL}, and HH_{LL}. All of the average energies will form a matrix with size 64×64 when the whole sub-blocks were computed completely.

Step4. Estimate the whole blocks' mean energy Eb of the sub-blocks B_k, as show in figure 5.(b). Then compare the threshold -value Ea with Eb:

$$TempAry(k) = \begin{cases} 1, & Ea < Eb \\ 0, & Ea > Eb \end{cases} \qquad (14)$$

Where TempAry is a provisional binary array with size 64×64 depend on Ea and Eb.

Step5. Combine the temporality matrix with random-permuted watermark by exclusive-or operation. That is

$$\textbf{Secret key} = \textbf{TempAry} \oplus \textbf{W} \qquad (15)$$

The secret key denotes a secret array, which is used as a key to extract watermark.

3.2 Extracting the watermark

Suppose $f'(x,y)$ is the watermarked image. Before the extracting process, we must turn $f'(x,y)$ into binary digital image to calculate its Zernike Moment factor and detect if it is scaled or rotated, as mentioned in section 2. If it has been altered, we can recover it by computing the modulus A'_{00} and A'_{11}.

Step1. To analyse the watermarked image by equation (11), (12) and the 2nd-level full--decomposed wavelet packet. The watermarked image $f'(x,y)$ is divided into sub-blocks B_k' with number of K (i.e. $\frac{M}{WR} \times \frac{N}{WC}$).

Step2. Calculate the average energy Ea' in low frequency band of the whole sub-blocks B_k'. And the totals Ea' are going to compose a threshold-matrix.

Step3. Estimate the mean energy Eb' of the entire sub-blocks B_k' in the image, then compare Ea' with Eb' to obtain a $EXT\_TempAry$:

$$EXT\_TempAry(k) = \begin{cases} 1, & Ea' < Eb' \\ 0, & Ea' > Eb' \end{cases} \qquad (16)$$

Step4. Combine the secret key recorded on section 3.1 with $EXT\_TempAry$ by exclusive-or operation, as equation (17). Then we will have the extracted random-permuted watermark $W'(i,j)$.

$$W' = key \oplus EXT\_TempAry \qquad (17)$$

Step5. Use the random seed recorded on section 3.1 to retrieve the watermark $W''(i,j)$.

4. EXPERIMENT RESULT

To test the robustness of this algorithm, we use Lena as a host image and a 64x64 binary image as a watermark. They are shown in figure 6.

In the general digital image processing, we usually measure the degree of the image distortion with the PSNR value (the peak signal-to-noise ratio). The PSNR value was defined as

***PSNR(dB)* =**

$$10\log_{10} \frac{I_{max}^2}{\frac{1}{M \times N} \sum_{x=0}^{M-1} \sum_{y=0}^{N-1} [f'(x,y) - f(x,y)]^2} \qquad (18)$$

where I_{max} =255,when the image is a 8 bit grey image. $M \times N$ is the size of image. f(x,y) is the original image and $f'(x,y)$ is the watermarked image. And we use a NC value(the Normalized Correlation) to express the quality of extracted watermark. The NC value was defined as

$$NC = \frac{\sum_i \sum_j W(i,j)W'(i,j)}{\sum_i \sum_j [W(i,j)]^2} \quad (19)$$

where $W(i,j)$ is the original watermark and $W'(i,j)$ is the extracted watermark.

(a) host image(512x512) (b) watermark(64x64)
figure 6 host image and watermark

4.1 Rotation attacks

If the watermarked image has been rotated, we can figure out the rotation degree ϕ by equation (8). Then we can re-rotate the watermarked image with the degree $-\phi$,and the embedded watermarked can be detected. Figure 7 shows the NC value of watermark between two experiments that one has been re-rotated with Zernike moment and the other has not been re-rotated.

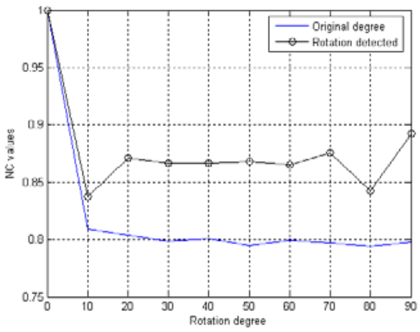


figure 7 the NC value of watermark between two experiments that one has been re-rotated with Zernike moment and the other has not been re-rotated.

4.2 Scaling attacks

If the watermarked image is tempered by scaling, we can detect the ratio by equation (111) and then we can retrieve it. Table 1 lists NC values of watermark with different scaling rate.

Table 1 NC values of watermark with different scaling rate

Scaling Rate	NC value
0.25	0.8125
0.5	0.8122
0.75	0.8381
0.9	0.8708
1	1
1.25	0.8948
1.75	0.9204
2	0.9261
3	0.913
5	0.9539
10	0.9618

4.3 JPEG compression attacks

Table 2 lists the NC values between the original watermarks and the extracted watermark that the watermarked images are attacked by JPEG compression. The experiments show that the watermark is still extracted successfully even by the quality 10.

Table 2 NC values between different compress qualities

JPEG quality	NC value
100%	0.9640
90%	0.8746
80%	0.8637
70%	0.8613
60%	0.8591
50%	0.8474
40%	0.8362
30%	0.8307
20%	0.8198
10%	0.8117

4.4 Cutting attacks

The relation between the NC value and the remaining ratio after cutting has been shown in table 3. Experiments show the watermark scheme was robust against cutting attacks.

Table 3 NC value and the remaining ratio after cutting

Remaining Ratio	100%	90%	80%	70%	60%	45%
NC	1	0.9436	0.9264	0.9024	0.8929	0.8635

4.5 Other attacks

Table 4 lists the NC values under other attacks such as 3×3 Low-pass filter, 5×5 Low-pass filter, 6% Gaussian noise and 10% Gaussian noise. Experiments show all of the NC values are above 0.8 under other attacks.

5.Conclusion

This paper proposes a robust watermark system that utilizes good geometry invariant characteristic of Zernike moment and Comparison of the average energy of wavelet packet. The experiments prove that the method is robust against scaled, rotated, blurred, cut and jpeg attacks. Particularly, the use of the Zernike moment improves the robustness against geometric attacks greatly. In future, we will study in watermark system under multi-attacks at the same time.

Table 4 NC value under other attacks

Attacks	NC value
Low-pass filter 3×3	0.8193
Low-pass filter 5×5	0.8168
Gaussian noise 6%	0.8395
Gaussian noise 8%	0.8228
Gaussian noise 10%	0.8160

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