Rotation, scaling, and translation invariant local watermarking technique with Krawtchouk moments

Li Zhang (张 力), Weiwei Xiao (肖薇薇), Gongbin Qian (钱恭斌), and Zhen Ji (纪 震)

Faculty of Information Engineering, Shenzhen University, Shenzhen 518060

Received July 12, 2006

A rotation, scaling, and translation invariant local watermarking is proposed with one or two Krawtchouk moment(s) of the original to estimate the geometric distortion parameters including rotation angle, scaling factor, and translation parameter. Krawtchouk moments can be used as private key of watermark extractor. Watermark is inserted into perceptually significant Krawtchouk moments of original, and watermark based on Krawtchouk moments is local. Independent component analysis (ICA) is utilized to extract watermark blindly. Experimental results show that this method has a good robustness against distortions preformed by watermark benchmark — Stirmark.

OCIS codes: 100.0100, 100.2000.

Digital watermarking technique[1] is an effective means to resolve copyright protection, information security problems by embedding watermark information into digital protected media[2]. However, recently it has become clear that even very small geometric distortions can prevent the watermark detection. This problem is most pronounced for blind detection. Alghoniemy *et al.*[3] presented a solution to estimate scaling factor and rotation angle assuming that detector has prior information regarding wavelet maxima of original images. Krawtchouk moment[4] is well suited for discrete spaces image since it is constructed from the set of Krawtchouk polynomials which are functions of a discrete variable. Unlike the conventional moments, Krawtchouk moments have the ability of being able to extract local features from any region-of-interest in an image.

This paper mainly discuss the proposal of a rotation, scaling, and translation invariant local image watermarking, which utilizes the Krawtchouk moments of original to estimate the geometric distortion parameters. Estimation method can be used as preprocess of detector to restore synchronization of watermarking. The work of estimating the geometric distortion parameters have been done by utilizing the geometric moments[5]. The watermark was generated independent of the original and was embedded by modifying Krawtchouk moments of the original image. The embedded watermark affects only a selected portion of the original image, which can be decided by user. This permits the watermark to be embedded at the portion of the image which is the most significant information-wise. And this also means that the watermark is especially robust to cropping. Independent component analysis (ICA) is utilized by detector to extract the perfect watermark blindly. Experiments results show that parameters of geometric distortions can be estimated with high precision and the proposed watermarking has a good robustness against variety of attacks performed by watermark benchmark — Stirmark.

Methodology of estimating geometric distortion parameters: Assume that the image is rotated by the center normalized as (0,0) without generality. So the rotation angle can be estimated by

$$\frac{(N-1)p_1Q'_{10}}{\Omega_{10}}\cos\theta+\frac{(M-1)p_2Q'_{01}}{\Omega_{01}}\sin\theta=\frac{(N-1)p_1Q_{10}}{\Omega_{10}}+\frac{Q'_{00}}{\Omega_{00}}[(N-1)p_1(1+\cos\theta)+(M-1)p_2\sin\theta], \quad (1)$$

where Q_{00}, Q_{10} and Q'_{10}, Q'_{01} are Krawtchouk moments of the original with size of $N\times M$ and the rotated watermarked image respectively. $\Omega_{nm}=[\rho(n;p_1,N-1)\rho(n;p_2,M-1)]^{-1/2}$. Suppose that $\Delta=\frac{(N-1)p_1Q'_{10}}{\Omega_{10}}\cos\theta+\frac{(M-1)p_2Q'_{01}}{\Omega_{01}}\sin\theta-\frac{(N-1)p_1Q_{10}}{\Omega_{10}}-\frac{Q'_{00}}{\Omega_{00}}[(N-1)p_1(1+\cos\theta)+(M-1)p_2\sin\theta]$. Once θ is satisfied by $\Delta<\varepsilon$, the estimated results will be obtained. ε is a small enough positive value and set $\varepsilon=10^{-5}$ in the experiments.

Suppose $f(\frac{x}{a},\frac{y}{b})$ is scaled image with size of $N'\times M'$ and set $r_0=M/N$. It can be deduced that $a/b=(N'/N)/(M'/M)=(N'/M')r_0$. The scaling factor can be estimated by one Krawtchouk moments

$$a=\sqrt[3]{((\frac{Q'_{00}}{\Omega_{00}}-(N-1)p_1\frac{Q'_{10}}{\Omega_{10}})N'r_0)\Big/((\frac{Q'_{00}}{\Omega_{00}}-(N-1)p_1\frac{Q_{10}}{\Omega_{10}})M')}, \quad (2a)$$

$$b=\sqrt[3]{((\frac{Q'_{00}}{\Omega_{00}}-(N-1)p_1\frac{Q'_{10}}{\Omega_{10}})M'^2)\Big/((\frac{Q'_{00}}{\Omega_{00}}-(N-1)p_1\frac{Q_{10}}{\Omega_{10}})N'^2r_0^2)}. \quad (2b)$$

Suppose c and d are the translation parameters in x and y directions respectively. So the translation parameters can be estimated by

1671-7694/2007/010021-04

$$c = (N-1)p_1 \frac{(Q_{10} - Q'_{10})\Omega_{00}}{\Omega_{10} Q'_{00}}, \quad d = (M-1)p_2 \frac{(Q_{01} - Q'_{01})\Omega_{00}}{\Omega_{01} Q'_{00}}. \tag{3}$$

It should be noted that if $(\frac{Q'_{00}}{\Omega_{00}} - (N-1)p_1 \frac{Q'_{10}}{\Omega_{10}})(\frac{Q'_{00}}{\Omega_{00}} - (N-1)p_1 \frac{Q_{10}}{\Omega_{10}}) < 0$, it can be judged that the image was flipped in x direction unless it is symmetric around y-axis, which is rare in real world images.

Image enhancement is a common manipulation and there are many kinds of ways to enhance images. Assume to use the contrast adjust to enhance the image. Suppose the gray scope of original image is $[t, s]$ and the gray scope of enhanced image, $g(x, y)$, is $[T, S]$. Then t and s can be estimated with Q_{10}

$$t = \frac{(-(N-1)p_1 \frac{Q'_{10}}{\Omega_{10}})(\frac{Q'_{00}}{\Omega_{00}} - (N-1)p_1 \frac{Q_{10}}{\Omega_{10}}) + S((\frac{Q'_{00}}{\Omega_{00}} - (N-1)p_1 \frac{Q_{10}}{\Omega_{10}}) \iint \mathrm{d}x\mathrm{d}y - \frac{Q'_{00}}{\Omega_{00}} \iint x\mathrm{d}x\mathrm{d}y)}{(\frac{Q'_{00}}{\Omega_{00}} - (N-1)p_1 \frac{Q'_{10}}{\Omega_{10}}) \iint \mathrm{d}x\mathrm{d}y - \frac{Q'_{00}}{\Omega_{00}} \iint x\mathrm{d}x\mathrm{d}y}, \tag{4a}$$

$$s = \frac{(-(N-1)p_1 \frac{Q'_{10}}{\Omega_{10}})(\frac{Q'_{00}}{\Omega_{00}} - (N-1)p_1 \frac{Q_{10}}{\Omega_{10}}) + T((\frac{Q'_{00}}{\Omega_{00}} - (N-1)p_1 \frac{Q_{10}}{\Omega_{10}}) \iint \mathrm{d}x\mathrm{d}y - \frac{Q'_{00}}{\Omega_{00}} \iint x\mathrm{d}x\mathrm{d}y)}{(\frac{Q'_{00}}{\Omega_{00}} - (N-1)p_1 \frac{Q'_{10}}{\Omega_{10}}) \iint \mathrm{d}x\mathrm{d}y - \frac{Q'_{00}}{\Omega_{00}} \iint x\mathrm{d}x\mathrm{d}y}. \tag{4b}$$

Watermarking embedding process: The embedding steps of this watermarking system are as follows. The watermark is created randomly and expressed by W, that is, the watermark is independent of the original image. Transform the original image $f(x, y)$ to $\bar{f}(x, y) = \frac{f(x,y)}{\sqrt{w(x;p_1,N-1)w(y;p_2,M-1)}}$. p_1, p_2, N, M, Q_{10} and Q_{01} are kept as secret key to increase the safety of the watermark. Sets of low order Krawtchouk moments $Q_\mathrm{w} = \{Q_{\mathrm{w}m_1,n_1}, \cdots, Q_{\mathrm{w}m_k,n_k}\}$ and $Q_\mathrm{o} = \{Q_{\mathrm{o}m_1,n_1}, \cdots, Q_{\mathrm{o}m_k,n_k}\}$ are constructed from the watermark and $\bar{f}(x, y)$ respectively. A set of adjusted Krawtchouk moment $\hat{Q} = \{\hat{Q}_{m_1,n_1}, \cdots, \hat{Q}_{m_k,n_k}\}$ is obtained to embed the watermark information

$$\hat{Q}_{m_i,n_i} = Q_{\mathrm{o}m_i,n_i} + \alpha(m_i, n_i)Q_{\mathrm{w}m_i,n_i}, \tag{5}$$

α is the embedding intensity of watermark which is the adopted characteristics of human visual system. Retrieve the watermarked image by the set of adjusted Krawtchouk moments.

Watermarking detection process: The watermark detection does not need the original image. ICA process is the core of the watermark detector accomplished by the FASTICA algorithm. The detection steps of this watermarking system are described as follows. Transform the corrupted image $z(x, y)$ to $\bar{z}(x, y) = \frac{z(x,y)}{\sqrt{w(x;p_1,N-1)w(y;p_2,M-1)}}$. The parameters of p_1, p_2 and N, M are kept as secret key used by the embedding processing. Before watermarking detection, the geometric distortion parameters are estimated according to the methodology of estimating geometric distortion parameters to restore synchronization of watermarking. ICA is utilized to extract the perfect watermark blindly[6].

Simulation results: The objective of this section is to provide the experimental validation of the theoretical framework discussed above. The watermark embedded is a local watermark in the sense that only a portion of the image will be affected by the watermark. The watermark is produced randomly with the same size as original image. Normalization correction (NC) is used to express the similarity between the original watermark and the extracted watermark quantitatively[6]. It is observed that the higher NC, the more similarity between the extracted watermark and the original watermark. Figure 1 gives original image and watermarked image. The estimation

Fig. 1. Original Lena image and watermarked image.

Table 1. Rotation Angle Estimation Compared with Ref. [3]

Factual	Estimated Angle	Result in Ref. [3]
0.1	0.09999999999404818	–
0.2	0.1999999999940482	–
−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	–

Table 2. Scaling Factor Estimation Scaled by Stirmark Compared with Ref. [3]

Factual	Estimated Data	Result in Ref. [3]
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	–

Table 3. Aspect Ratio Estimation Scaled by Stirmark

Flipping	Factual Factor in x	Factual Factor in y	Estimated x	Estimated y
1	0.5	0.75	0.4988	0.7482
1	1.5	1.75	1.4999	1.7499
1	1.25	1.5	1.24999	1.49999
0	1.25	1.5	1.2495	1.4994

Table 4. Translation Parameters Estimation Translated by Stirmark

X Factual	Y Factual	Estimated x	Estimated y
1	1	1.000000000000291	1.000000000000214
1	2	1.000000000000291	2.000000000000157
3	5	3.000000000000564	5.000000000000837
5	5	5.000000000000258	5.000000000000837
10	20	10.00000000000156	20.00000000000192
30	30	30.00000000000348	30.00000000000282

Table 5. Image Enhancing Parameters Estimation

	Gray Scope of Enhanced Image	Estimated Gray Scope of the Image	Gray Scope of the Original Image	Correlation between Original Image and the Restored Image
Min	0.2	0.02745098039191914	0.02745098039215686	
Max	0.9	0.9921568627454210	0.9921568627450981	1
Min	0.3	0.02745098039295670	0.02745098039215686	
Max	0.7	0.9921568627438852	0.9921568627450981	1
Min	0.5	0.02745098040473985	0.02745098039215686	
Max	0.6	0.9921568627263803	0.9921568627450981	0.9999999999999992

Table 6. Rotation Angle and Scaling Factor Estimation

Angle	X Factor	Y Factor	Estimation Angle	Estimated x Factor	Estimated y Factor
2	0.5	0.5	2.0000000000004	0.49874	0.49874
2	2.0	2.0	2.0000000000004	2.00251	2.00251
2	1.25	1.5	2.0000000000004	1.25083	1.50099
−1	1.5	1.5	−0.99999999998	1.50126	1.50126
−1	1.25	1.5	−0.99999999998	1.25084	1.50101

Table 7. Translation and Scaling Factor Estimated by Stirmark

Angle	X Translation	Y Translation	Estimated Angle	X Estimated Translation	Y Estimated 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	15	15	1.25066896517105	15.00132235690322	15.00081599259033
1.5	10	20	1.5013265776978	9.99802735395312	20.001763432857
2.00	15	15	2.00250627350094	15.00000024777901	14.99999989545282

results are listed in Tables 1 and 2. Flipping and aspect ratio parameters can also be estimated and the results are shown in Table 3, where Flipping = 1 means flipping occurred and Flipping = 0 means no flipping occurred. Tables 4 and 5 list translation parameters estimation results and image enhancement results, respectively. Tables 6 and 7 list rotation and scaling parameters estimation results and translation and scaling estimation results, respectively. Since the watermark embedded is local, the watermarking is especially robust to cropping. Note

Table 8. Robustness Against Cropping

Attacks	Crop to 224 × 224	Crop to 217 × 217	Crop to 192 × 192
NC	0.9754	0.9911	0.9873

Table 9. Robustness to Additive Noise

Noise Type	Gaussian Noise, $\mu = 0$, $\sigma^2 = 0.1$	Gaussian Noise, $\mu = 0$, $\sigma^2 = 0.3$	Salt & Pepper 20%	Salt & Pepper 30%	Speckle $\mu = 0$, $\sigma^2 = 0.2$	Speckle $\mu = 0$, $\sigma^2 = 0.3$
NC	0.9901	0.9893	0.8308	0.7980	0.9105	0.7223

Table 10. Robustness to JPEG Compression Produced by Stirmark

Q	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	0.9958	0.9931	0.9924	0.9919	0.9887	0.9812	0.9500	0.9213	0.8278

Table 11. Experimental Results Compared to Ref. [7] and Two Commercial Watermark Techniques

Attack	Results in Ref. [7]	Digimarc Technique	Suresign Technique	Method Proposed
Scaling	0.78	0.72	0.95	1
Rotation	1	0.94	0.5	1
Flipping	1	–	–	1
Translation	–	–	–	1
Random Geometric Distortion	0	0.33	0	1
JPEG Compression	0.74	0.81	0.95	0.96
Cropping	0.89	–	–	0.95
Additive Noise	–	–	–	1

that not all portion of image is significant information wise. Some portions of an image are more crucial when compared with others, for example, the subject-matter of an image may be more important than the background. Hence, it is up to the discernment of the user to decide where the watermark should be placed, and in our case, this means adjusting the parameters $[p_1, p_2]$ accordingly. Experiments were done to test the robustness against cropping and the results are listed in Table 8. Generally, lower order Krawtchouk moments of the image capture the low spatial frequency features of an image, while the higher order ones capture the high frequency features of an image. Since the noise can be seen as the high frequency features of the image, it is shown that by reconstructing an image with just its lower order moments and using only a partial lower order moment, noise could be removed. The experimental results show that images degraded by Gaussian, salt-and-pepper, and speckle noise can be restored with Krawtchouk moments and the results are listed in Table 9. JPEG compression causes the high frequency components of an image to be attenuated. Experiments were performed to examine the robustness of the proposed watermarking to JPEG compression produced by Stirmark with different qualify factors Q from 90 to 10 and the results are listed in Table 10. Experimental results were compared with those of method proposed in Ref. [8], which proposed a digital watermarking technique in discrete Fourier transform (DFT) domain and some commercial watermark techniques and the results are shown in Table 11.

In conclusion, a rotation, scaling, and translation invariant blind local image watermarking technique is proposed, which estimates the geometric distortion parameters for a corrupted watermarked image by Krawtchouk moments of the original image. Krawtchouk moments of the original can be used as private key of watermark extraction process. Suppose the detector does not know any information about the attacks and the detection does not need the original image. Experimental results show that the proposed image watermarking is robust against image processing, such as scaling, translation, rotation, additive noise, and image compression.

This work was supported by the National Natural Science Foundation of China under Grant No. 60502027. L. Zhang's e-mail address is wzhangli@szu.edu.cn.

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