An Efficient Print-scanning Resilient Data Hiding Scheme Based on a Novel LPM

Xiangui Kang[1], Xiong Zhong[1], Jiwu Huang[1], Wenjun Zeng[2]

1. School of Information Sci. & Tech., Sun Yat-Sen Univ., China. {isskxg, isshjw}@mail.sysu.edu.cn
2. Dept. of CS, Univ. of Missouri-Columbia, MO 65211, U. S. A. zengw@missouri.edu

ABSTRACT

Print-scan resilient data hiding has not been extensively researched. This paper presents an efficient multi-bit blind watermarking scheme based on a novel Fourier log-polar mapping (LPM). The watermark resynchronization after print-scanning is efficiently solved by an embedded tracking pattern which cannot be removed by template removing attacks and is not detectable for a malicious part. Experimental results show that the proposed watermarking scheme has excellent robustness to print-scanning, cropping, geometric distortion and JPEG compression etc. The obtained success ratios of extraction 60 bits message without error from the combination attack of JPEG compressed with quality factor of 50-100 and then print-scanning were at least 95%.

***Index Terms*—**Data hiding, LPM, geometric distortion, print-scanning

1. INTRODUCTION

Print-scanning resilient data hiding provides a viable authentication mechanism via the multi-bit watermark hidden in a picture in the document. Document authentication of ID card, passport, driving license etc. is important today as the security concerns are higher than ever before. But print-scanning resilient data hiding has not been extensively researched. Many of them focus on detecting watermarks [1-2]. In this paper, we propose an efficient multi-bit watermarking scheme based on a novel discrete log-polar mapping which is robust to general geometric distortion (in digital form), JPEG compression and print-scanning simultaneously.

2. LIMITATION OF EXISTING LPM-BASED WATERMARKING

The image Fourier log-polar domain simplifies the effects of rotation, scaling and translation (RST) transforms to shifts. LPM-based watermarking [1-2] eliminates the need to invert geometric distortions, thus it can be one potential efficient way to extract a watermark from geometric distorted images. But the existing methods impose limitation on the cardinality of the watermark (that is, limit the embedding space) in order to avoid watermark/image distortion induced by embedding. This is believed to be a major limiting factor to the capacity and/or the performance of the LPM watermarking schemes [3]. Furthermore, the robustness against print-scanning of a LPM based watermarking needs to be investigated.

3. DATA EMBEDDING BASED ON A NOVEL LPM

In this paper, we propose a novel Fourier log polar mapping method as follows.

Firstly, we apply a discrete log polar transform to the Fourier magnitude coefficients' Cartesian coordinate, then the resulting log polar coordinate is linked to a watermark matrix's index, thus constructing a generally many-to-one mapping from magnitude spectrum coefficients to the watermark bits to be embedded. As a result, one sampling point in the DFT domain is (inversely) mapped onto by only one point in the LPM domain. Secondly, we adopt a value close to 1 for the base a (refer to Eq. (1) below) of the log polar, thus the sampling interval of the discrete log polar transform is nearly uniform to achieve a good mapping from the Cartesian plane to the log polar plane. Thirdly, A tracking sequence is used to resynchronize informative watermark, not bear information itself. We embed the tracking sequence and the informative watermark in the same way, apply the correlation theorem to achieve a fast computation of the cross phase correlation between the tracking sequence and the image log polar mapping magnitude spectrum, then find the maximum correlation to locate the informative watermark.

The proposed watermark embedding process is shown in Fig. 1 and described as follows in detail.

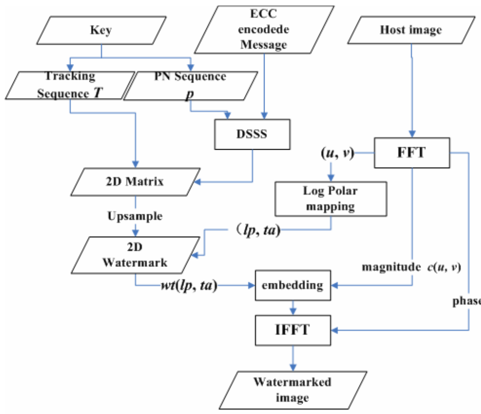


Fig. 1. The schematic illustration of watermark embedding

Watermark formation. Based on a key k_w, we generate a bipolar tracking sequence $\boldsymbol{T}$ of length N_T and a N_p-bit bi-polar PN-sequence $\boldsymbol{p}=\{p_j\}$ respectively. A L-bit message $\boldsymbol{m}$ $\{m_i;\ m_i\in\{0,1\}\}$ is first encoded using an error correction code (ECC) to obtain the message $\boldsymbol{m_c}$ $\{m_{ci};, m_{ci}\in\{0,1\}\}$ of length L_c. Then each m_{ci} is direct sequence spread spectrum (DSSS) encoded using $\boldsymbol{p}$, where a bit of "1" is encoded as a bipolar spread spectrum sequence $W_i\{w_{ij};0\le j<N_p\}=+1\times\boldsymbol{p}$, and a bit of "0" as $W_i=-1\times\boldsymbol{p}$. Then we arrange all tracking sequence bits and all DSSS encoded bits into a 1D sequence sequentially. We arrange all bits from the obtained 1D sequence column by column to form a $M/2\times N/2$ 2D matrix. Then the obtained matrix is upsampled, along the row and column respectively, by a factor of 2 (in our implementation, each row is repeated once to obtain an intermediate matrix, then each column of the intermediate matrix is repeated once) to obtained an oversampled version, $M\times N$ 2D matrix $\mathbf{WT}$ $\{wt(m,n)\}$, in order to better resist the image corruption. $\mathbf{WT}$ consists of the 2-D tracking pattern $\boldsymbol{T}_{\mathrm{m}}$ and the informative watermark portion $\mathbf{W}$. Larger is N_T, the watermark may be resynchronized more precisely, but smaller is the bits of $\mathbf{W}$, thus the message would be less robust. We observe that the cost of having N_T being 20% (an empiristical value) of the total bits ($M/2\times N/2$) is a good choice to achieve a good compromise between tracking the resynchronization location accurately and decoding the message $\boldsymbol{m}$ correctly.

Log polar mapping. Apply 2-D DFT to a host image, and shift the DC component to the center of the Fourier magnitude spectrum. Then apply the discrete log-polar transform as shown in Eq. (1), to the Fourier coefficients' Cartesian coordinate (u, v) (normalized frequencies) or polar coordinate (r, θ) to obtain the discrete log-polar coordinate ($l\rho$, ta).

$$\begin{aligned} l\rho &= floor(\log_a \frac{r}{R})+o \\ ta &= floor(N\times\theta/\pi) \end{aligned} \tag{1}$$

where $r=\sqrt{u^2+v^2}$, $\theta=\arctan(u/v)$, $floor$ means floor operation. R is called the origin frequency in this paper as $r=R$ results in a zero for $\log_a \frac{r}{R}$. R is chosen to be about 0.18 because watermark is embedded in low and middle frequencies to achieve a better compromise between robustness and invisibility, and achieve better resistance to print-scanning [5]. o is a constant to assure $l\rho\ge 0$, here $o=M/2$. We choose $a=2^{1/M}$, which is almost equal to 1 for large M, thus the sampling interval of the discrete log polar transform is nearly uniform along the log radius axis to achieve a good mapping from the Cartesian plane to the log polar plane. It is noted that, unlike our careful selection, the base a of LPM is often chosen to be e [1-2]. r (the polar of the chosen embedding magnitude coefficient) meets $R\times a^{-M/2}\le r<R\times a^{M/2}$. So the watermark embedding area is a circular area, and its discrete log-polar coordinate ($l\rho$, ta) corresponds to the index of the 2D watermark matrix $\mathbf{WT}$. It is easy to prove that $0\le l\rho<M$, $0\le ta<N$. In the actual embedding, all the magnitude coefficients with the same discrete log-polar coordinate ($l\rho$, ta) are embedded with the same watermark bit $wt(l\rho, ta)$ due to this many-to-one log polar mapping.

Data embedding. The watermark is embedded using an additive method as illustrated in Eq. (2) or a multiplication method as in Eq. (3). The watermark is embedded in a Fourier magnitude coefficient according to its corresponding discrete log-polar coordinate ($l\rho$, ta).

$$c'(u,v)=c(u,v)+\alpha\times wt(l\rho,ta) \tag{2}$$

$$c'(u,v)=c(u,v)\times(1+\alpha\times wt(l\rho,ta)) \tag{3}$$

where $c(u, v)$, $c'(u, v)$ are Fourier magnitude coefficients before and after embedding. α is the embedding strength, for example, α may be chosen to be 0.20~0.25 in our work to reach a good compromise between robustness and invisibility of watermark. Note that one advantage of implementing watermark embedding in the Fourier magnitude domain is the ease in controlling the watermark energy associated with each Fourier coefficient which facilitates perceptual quality control. The proposed watermark embedding in the Fourier magnitude domain is equivalent to embedding in the Fourier log-polar domain. If the watermarked image is rotated, the watermark in the Fourier log-polar domain will be cyclically shifted along the angle axis; if the watermarked image is scaled, the watermark in the Fourier log-polar domain will be shifted along the log-radius axis [1]. The tracking pattern $\boldsymbol{T}_{\mathrm{m}}$ will be used to track the shifts.

IDFT. Finally the IDFT is applied to the changed Fourier coefficients to obtain the watermarked image.

4. RECOVERY OF EMBEDDED DATA

The watermark extractor does not have any prior knowledge of the original image. The tracking sequence and the original *PN*-sequence $\boldsymbol{p}$ may be generated by a key, which is known to the detector. The data extraction includes following steps.

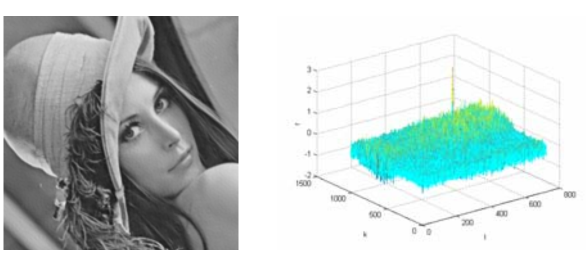
Fourier Log-polar mapping. We apply the log-polar transformation shown in as Eq. (1) to the DFT magnitude coefficients, as is done in embedding, to obtain the discrete log-polar coordinate ($l\rho$, ta). Here r meets $a^{-\lambda M} \times R \le r < a^{\lambda M} \times R$, where λ is a parameter to control the size of the tracking area (the area within which we use the tracking sequence to track the location of the watermark). A larger λ results in a larger tracking area, thus might provide resistance to larger rescaling distortion (because a lager rescaling in the spatial image results in a larger reciprocal rescaling in the frequency domain [1], then leads to a lager shift along the log-radius axis). But a larger tracking area might result in a false tracking and require a larger computation load. In our work, λ is chosen to be 1 to avoid false tracking and achieve a compromise. Because it is a many-to-one log-polar mapping, we compute the mean of all magnitude coefficients with the same discrete log-polar coordinate to obtain a log-polar mapping matrix $mag(m,n)$ $(0 \le m < 2\lambda M, 0 \le n < N)$.

Watermark auto-resynchronization. Phase is very important information to align two images which are shifted relative to each other [2]. We adopt the following cross phase correlation method to find the matching location. $\mathbf{T}_{\mathrm{m}}$ (2D tracking pattern) is padded with 0s to the same size of $mag(m,n)$ to obtain a new matrix $g(m, n)$. The cross correlation is calculated as follows.

$$r(k,l) = IFFT[e^{j\phi_{\mathrm{MAG}}(u,v)} G^*(u,v)] \tag{4}$$

where $MAG(u,v) = DFT(mag(m,n))$, $G(u,v) = DFT(g(m,n))$, $\phi_{MAG}(u,v)$ is the phase of $MAG(u,v)$, "*" refers to the complex conjugate operation. Then we find the maximum cross correlation of $r(k,l)$ (see, e.g., Fig. 2(b)) to locate the matching position. We then obtain the resynchronized magnitude coefficients MxN matrix $\hat{mag}_u(m,n)$ which has been embedded with the watermark **WT** [2]. The $\hat{mag}_u(m,n)$ is then downsampled to obtain a $M/2$x$N/2$ magnitude coefficients matrix $\hat{mag}(m,n)$. In the implementation, for each element of $\hat{mag}(m,n)$, we compute the average of its values at 4 repeat positions in matrix $\hat{mag}_u(m,n)$, corresponding to the upsampling mentioned in Section 3.

Despread and decoding We then extract N_p magnitude coefficients from matrix $\hat{mag}(m,n)$ to form a sequence W_i^* which corresponds to the embedded spread spectrum sequence W_i, and correlate it with the original PN sequence $\boldsymbol{p}$. If the normalized correlation is larger than 0 (positive correlation), the extracted bit m_{ci}^* is determined to be "1", *i.e.* $W_i = \boldsymbol{p}$ has been embedded; Otherwise, m_{ci}^* is decided in favor of "0", *i.e.* , W_i =-1×$\boldsymbol{p}$ has been embedded. According to our experiments, print-scanning changes this correlation relation (*i.e.* from positive correlation to negative correlation or vice versa) little, thus this extraction method can be robust to print-scanning. Finally the obtained sequence $\boldsymbol{m}_c^*$ is ECC decoded to recover the L-bit message $\boldsymbol{m}^*$.



(a) (b)

Fig. 2 (a) A watermarked image rotated by 45°, cropped for reframing, then scaled back to 512×512. The 60-bit message can be recovered without error; (b) The corresponding peak of the cross correlation.

5. SIMULATION RESULTS

The proposed watermarking scheme is applied on a variety of images. The representative result on "Lena", "Peppers" and "Baboon" is reported here. In our simulation, the BCH (72, 60) code is adopted, which can correct up to 5 bits of error. We choose M = 64, N = 360, N_p = 64. The PSNRs (peak signal noise ratio) of the watermarked "Lena" , "Peppers" and "Baboon" images are 43.0dB, 43.0dB and 38.0dB respectively. The watermark is not visible. The watermark extraction is very fast, only takes about 0.3 seconds on a computer with a 2.8 GHz Intel Pentium CPU.

The proposed scheme is robust to rescaling with the scale factor between 0.6 and 2.0 (rescaling_0.6~2.0), cropping of 75% of image pixels, translation, rotation by any degree. In

(a) 546×594 (b) 632×673 (c) 679×634 (d) 550×594

Fig. 3 Print-Scanning images and their size.

particular, the watermark is robust to Rotation, Scaling, and Cropping combination distortion (RSC) with any rotation angle in Stirmark 4.0, that is, RSC_0°~ RSC_180°. One example of RSC_45º is shown in Fig. 2. The 60-bit message survives the attacks in all the cases for all the images tested.

Particularly, the proposed watermarking scheme is robust to the combination attack of PEG compression and print-scanning (PS). For every test image ("Lena", "Baboon" or "Peppers"), we choose 10 random key k_w to generate 10 watermarked images. Each watermarked image was JPEG compressed with quality factor (QF) of 100, 80 and 50 respectively. The watermarked and JPEG compressed images are printed by *HP Color LaserJet 2600n* with a resolution of 300 dpi (dot per inch) first, then scanned with the resolution of 100ppi (pixels per inch) with random placement of the print on the flatbed of the *HP SCANJET 8300* scanner. The scanner automatically adjusts the brightness, contrast, gamma correction and all other settings. After scanning, we obtain the scanned images (Fig.3) from the scanner automatically which are saved in .Tiff Format file. Each watermarked and JPEG compressed image is printed then scanned 10 times. Thus for every test image and with some JPEG QF, we obtained 100 samples. We use Table 1 shows the experimental results of average bit error rate (BER) before decoding of the watermark and the success ratios of extraction 60 bits message without error from 100 samples. It is observed that with JPEG compression QF 100 (JPEG_100), the success ration is 100%. With JPEG_50, the success ration is larger than 95%, and is 100% for Baboon and Peppers, and BER before decoding is less than 0.034.

Compared with the state of the art works in [4-6], one achievement is that our proposed scheme don't need to invert the geometric distortion, thus the proposed watermark extraction is very efficient. Furthermore, the embedded template in DFT [4] [7] may be removed by a template attack, while the tracking pattern in this scheme cannot be easily removed because the energy of the tracking pattern is not distributed only on a small number of points and the detection of the tracking pattern is key dependent. Compared with the scheme in [5][6], the advantage of our proposed scheme is the robustness against geometric distortion, cropping and print-scanning simultaneously, the original image size is not necessary to be known to the decoder. Note that the PSNR of the watermarked "Lena" in our work is 3dB larger than that in [4][5], thus may achieve better invisibility.

Table 1. The results of PS with different JPEG quality

	Lena		Baboon		Peppers	
JPEG QF	Success ratio	BER	Success ratio	BER	Success ratio	BER
100	100%	0.003	100%	0.004	100%	0
80	98%	0.010	100%	0.004	100%	0.003
50	95%	0.034	100%	0.004	100%	0.005

6. CONCLUSIONS

An efficient print-scanning resilient data hiding based on a novel LPM is proposed in this paper. The proposed mapping expands the embedding space significantly (from about 100 [1-2] to 64x360/4 = 5760 in this work). The advantages of our proposed scheme are as follows.

1) The proposed multi-bit watermarking is robust to JPEG compression, geometric distortion, cropping and print-scanning simultaneously.

2) The watermark extraction is very efficient and fast. It has self resynchronization capability. It is not necessary to invert the geometric distortion in watermark extraction, although the embedded tracking pattern may be used as a template to identify the geometric distortion.

3) The detection of tracking pattern is key dependent, so it is not detectable for a malicious party. Furthermore, it cannot be easily removed.

Compared to the prior works [4-6], our scheme achieves significant improvement in terms of efficiency of blind multi-bit watermark synchronization, and the robustness to print-scanning and geometric distortion at the same time.

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