A PRACTICAL PRINT-SCAN RESILIENT WATERMARKING SCHEME

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ABSTRACT

A blind Print-Scan (PS) resilient watermarking scheme is proposed in this paper. By employing a series of novel solutions in block classification and different block-based embedding strategies, we achieved a good performance in terms of watermark capacity, robustness and image quality. The experimental results further demonstrate the validity of our proposed scheme.

1. INTRODUCTION

There have been growing interests and demands from academic and industry, in the area of print-scan resilient watermarking aiming at the applications such as copyright protection or authentication.

Basically the existing PS watermarking schemes can be roughly classified into two categories: halftone-based and RST (rotation, scaling and translation) invariant based. In the first category, watermark is embedded during halftoning process by slightly modifying the mechanisms of halftone image generation [1]; or, visual patterns, generated from the watermark, are embedded into two or more halftone images in such a way that the watermark can be perceived directly when halftone images are overlaid each other [2]. However, the design of halftone image watermarking scheme usually involves specific halftone technologies [1] or the resolutions of printer and scanner [2], which limits its applications. In the second category, the PS process is considered as a black box and the distortion introduced by this box is modeled as geometric (or RST) distortion and intensity distortion. Due to the difficulty of distortion modeling and the complexity of actual PS procedure, most state-of-the-art PS resilient watermarking schemes are only RST resilient schemes.

RST resilient watermarking schemes can be further classified into two types based on how to overcome the synchronization problem. The first type of schemes overcomes the synchronization problem by embedding watermark in the RST invariant transform such as Fourier-Mellin Transform (FMT) [3] or its variation [4]. The second type of schemes overcomes this problem by embedding an imperceptible synchronization pattern [5]. Although no synchronization pattern is required in the first type, its capacity is smaller and its complexity is higher than the second type. One common issue of these two types of watermarking schemes is it is hard to select the watermarking areas within an image because the watermark information is cast into the whole image. Therefore they are not suitable for some specific printing applications, in which some areas in the image need to be preserved (i.e., un-embeddable areas). For example, a compound image may consist of the background bitmap-based image and the foreground vector-formatted drawing /texts. Printing a compound image usually involves multi-layer printing process: the background image is firstly printed and the foreground drawings/texts are then overlapped onto the printed background image. In such applications, the area with drawings/texts should not be embedded with anything to maintain the robustness.

In this paper, after studying some properties during PS, we propose a new watermarking scheme, which is robust to both geometric distortion and intensity distortion. The watermark is embedded block by block in the DFT domain to make the watermarking flexible and gain in a good watermark capacity. Different embedding strategies are applied to different types of blocks, in an optimized way, to improve the image quality. The paper is organized as follows. Section 2 summaries some discovered PS properties. The proposed watermarking scheme is given in Section 3. Experimental results are presented in Section 4. We conclude the paper in Section 5.

2. SOME PROPERTIES OF PRINT-SCAN

The distortion during PS is printer/scanner dependent and time-variant even for the same printer or scanner. So it is very difficult to analytically model it. So empirically studying the PS properties becomes a natural solution to design a PS resilient watermarking scheme. Solanki [6] studied the PS properties of the magnitudes of the DFT coefficients:

(a) The low / middle frequency coefficients are preserved much better than the high frequency ones.
(b) In the low / middle frequency bands, the coefficients with low magnitudes see a higher noise than their neighbors with high magnitudes.
(c) Slightly modifying the low frequency coefficients with high magnitude is not significantly perceptible.

To design a delicate watermarking scheme, we find that the above PS properties are not enough. After conducting PS tests on tens of typical images on different printers and scanners with different resolutions repeatedly, we also find the following PS properties:

(d) Most textures can be preserved, or, most relationships between DFT coefficients are preserved though individual DFT magnitude may vary.

(e) The dynamic range of intensity values is reduced, as shown in Fig.1 (a). The range originally between 0-255 becomes 70-220 after PS. The dark areas become brighter while the bright areas become darker.

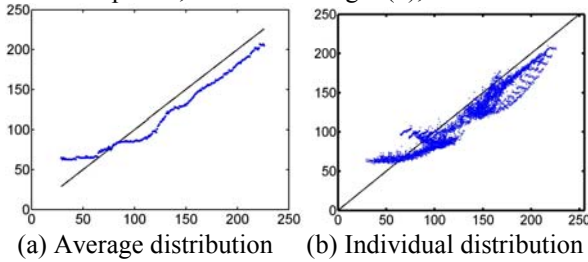(f) The distribution of pixel values after PS looks roughly like a spindle, as shown in Fig.1 (b), is bounded.

(a) Average distribution   (b) Individual distribution

Fig.1 The intensity distribution of PS process. X-axis represents the original intensity while Y-axis represents the print-scanned intensity.

3. PROPOSED SCHEME

Based on the above-observed properties of PS process and the requirements of PS watermarking scheme, we propose a new PS resilient watermarking solution, shown in Fig.2. The image is divided into the blocks with size M x M; watermark is then embedded block by block. The selected block is classified into smooth or texture type. Two different embedding methods are applied based on its block type. An optimization is employed to balance between image quality and the robustness. The watermark extraction is an inverse procedure of the watermark embedding.
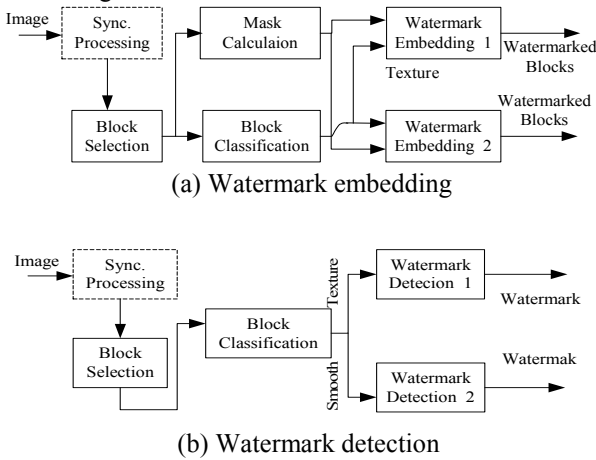

(a) Watermark embedding

(b) Watermark detection

Fig.2 Block diagram of the proposed scheme

Note that in our scheme, we exploit Hough Transform [7] to detect the boundaries of the printed image for watermark synchronization. We skip its details here due to the limits on paper length.

3.1. Block classification

From the PS properties (a), (b) and (c), we know that the watermark should be embedded into the DFT coefficients with low / middle frequencies. To reduce visual distortion, we choose the middle frequency DFT coefficients for embedding. However, modification on middle frequency coefficients in smooth area still significantly degrades the visual quality. So, we classify blocks into smooth block and texture block and employ different watermarking schemes for different types of block. In this subsection, we shall describe the algorithm of block classification.

Let $F_{u,v}$ represent the magnitude of a DFT coefficient located in position (u,v), the block is regarded as a texture block if Eq. (1) is satisfied. Here, we have shifted the DC coefficient to the center of the DFT block.

$$\sum_{v>0,u \quad 0, u=-M/2, \sqrt{u^2+v^2}<r}^{(M/2)-1} |F_{u,v}| \quad > \quad Th_1 \qquad (1)$$

where r and Th_1 are two parameters to be estimated.

In Eq. (1), we discard the DFT coefficients located in horizontal axis and vertical axis, as shown in Fig.3. This could avoid the effect of well-known "cross artifact" caused by the rectangular boundary of an image or a block, in which the DFT coefficients along the cross have much larger magnitude. Another benefit of doing so is discussed in the next section: The distortion caused by watermarking will not affect the block classification during watermark detection.

Note that due to property (e), to improve the robustness of watermarking scheme, we also classify the block whose average intensity exceeds the range between 70 and 220 as the texture block. This is because texture is usually better preserved after PS (Property (d)).
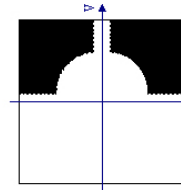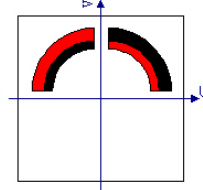

Fig.3 DFT coefs used for block classification

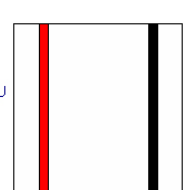**Fig.4** Area for texture block watermarking

Fig.5 Area for smooth block watermarking

3.2. Watermark embedding and extraction

3.3.1. Texture block

For texture block, watermarking is performed in the DFT domain since its inefficiency in energy compaction [8], in

other words, the number of non-zero coefficients with middle frequency is greater than other transforms such as DCT. The good property of DFT to RST is another consideration. The watermark is embedded in the middle frequency coefficients, shown as the marked area in Fig.4.

For the convenience of description, we denote the red and black areas in second quadrant as Area 1 and Area 2 and the red and black areas in first quadrant as Area 3 and Area 4; the energies of Area 1 to Area 4 are defined as E_1, E_2, E_3 and E_4, which can be calculated as

$$E_m = \sum_{(u,v)\ Area\ m} |F_{u,v}| \quad m = 1,2,3,4 \tag{2}$$

Now, we describe how to design the watermarking scheme. Firstly, since most relationships between DFT coefficients are preserved after PS (Property (d)), we employ the relationship between DFT coefficients to embed the watermark. Secondly, from Fig.1, we see that the relationship will preserve better if two groups of DFT coefficients are employed instead of two individual DFT coefficients. By using relationship between two groups of coefficients for watermarking, even if the RST parameters could not be accurately estimated during synchronization, its impact on watermark detection could still be reduced [9]. The watermark is embedded until Eq.(3) is met.

$$\begin{cases} (E_1' + E_3') - (E_2' + E_4') > TH_2 & watermark\ bit = 1 \\ (E_2' + E_4') - (E_1' + E_3') > TH_2 & watermark\ bit = 0 \end{cases} \tag{3}$$

where E_1', E_2', E_3' and E_4' are the watermarked values of E_1, E_2, E_3 and E_4; Th_2 can be calculated as

$$Th_2 = \max(C_1, C_2) \tag{4}$$

where C_1 is a pre-defined constant; C_2 is related to the complexity (texture measure) of individual block (Eq. (1)).

Note that in Eq. (3), each group of DFT coefficients comes from two different areas to reduce the visual quality degradation caused by watermarking. This is because $E_1 + E_3$ is very close to $E_2 + E_4$ in most image blocks. To further improve the visual quality of the watermarked image, the watermarked block is firstly converted back to pixel domain using IDFT; then the difference between the original and watermarked pixels ($f_{x,y}$) should be adjusted to $f_{x,y}'$ according to Eq. (5):

$$f_{x,y}' = \begin{cases} f_{x,y}, & if\ |\ f_{x,y}\ | < jnd_{x,y} \\ sign(\ f_{x,y})jnd_{x,y}, & otherwise \end{cases} \tag{5}$$

where $jnd_{x,y}$ is the Just Noticeable Distortion (JND) of pixel (x, y) calculated by using Lie's algorithm [10]. Such a difference adjustment will usually reduce the difference between $E_1 + E_3$ and $E_2 + E_4$. Therefore, to

balance the visual quality and robustness, watermark embedding and difference adjustment are processed recursively until both Eq.(3) and Eq.(5) are satisfied. Such a recursive process could be considered as a simple version of optimization.

3.3.2. Smooth block
For smooth block, watermarking is performed in the pixel domain. We again use the relationship between two groups of pixels, as shown in Fig.5. The red area is denoted as Area 1 and the black area is denoted as Area 2.

The watermark is embedded as

$$\begin{cases} f_{x_1,y} = f_{x_1,y} + \quad, f_{x_2,y} = f_{x_2,y} - \quad, wmkbit = 1 \\ f_{x_1,y} = f_{x_1,y} - \quad, f_{x_2,y} = f_{x_2,y} + \quad, wmkbit = 0 \end{cases} \tag{6}$$

where $f_{x,y}$ is the pixel value and is the average value of $jnd_{x,y}$ on the block.

For both texture and smooth blocks, the watermark is extracted by directly comparing the difference between the two formed groups and no watermark is embedded in this block if two values are very close (below the threshold).

3.3.3. Constant block type
Now we discuss how to maintain the block type after watermark embedding so as to avoid the misclassification during watermark extraction.

For smooth block, we suppose $f(x, y)$ be the modification on pixel values caused by watermarking; the watermark bit is set as 1 without loss of generality. $f(x, y)$ can, therefore, be expressed as

$$f(x, y) = \begin{cases} , & (x, y)\quad Area\ 1 \\ - , & (x, y)\quad Area\ 2 \\ 0, & otherwise \end{cases} \tag{7}$$

Suppose $F(u, v)$ is the modification of DFT coefficients, it can be expressed as

$$F(u, v) = \sum_{x=0}^{M-1}\sum_{y=0}^{M-1} f(x, y)\exp(-j2\ \frac{ux+vy}{M}) \tag{8}$$

$$= \ *(\sum_{y=0}^{M-1}\exp(-j2\ \frac{ux_1+vy}{M}) - \sum_{y=0}^{M-1}\exp(-j2\ \frac{ux_2+vy}{M})) \tag{9}$$

$$= \ *(\exp(\frac{-j2\ ux_1}{M}) - \exp(\frac{-j2\ ux_2}{M}))\sum_{y=0}^{M-1}\exp(-\frac{j2\ vy}{M}) \tag{10}$$

Eq. (10) can be further rewritten as

$$F(u,v) = \begin{cases} M\ *(\exp(\frac{-j2\ ux_1}{M}) - \exp(\frac{-j2\ ux_2}{M})) & v = 0 \\ 0 & v\quad 0 \end{cases} \tag{11}$$

From Eq. (11), we can claim that watermarking in the smooth block only changes those DFT coefficients on the horizontal axis. Therefore, the watermarking in smooth block will not affect the results of block classification

because the DFT coefficients on the horizontal axis have been excluded during block classification (See Fig. 3).

As to the texture block, block type can also be easily maintained if we introduce another constraint Eq. (12) during watermarking. This constraint is easy to be obeyed.

$$(E_1' + E_3') + (E_2' + E_4') = (E_1 + E_3) + (E_2 + E_4) \quad (12)$$

4. EXPERIMENTAL RESULTS

We evaluate the proposed algorithm using 9 typical test images, as indicated in Table 1. For the convenience of comparison, all images are scaled to size 512x512. The block size is set to 16x16. So the maximum watermark capacity is 1024 bits. The PSNRs of the watermarked images are presented in Table1. We can see that visual quality of the watermarked image is acceptable for most PS related applications.

Table 1 PSNRs of the watermarked image

Image	Bike	Cafe	Splash	Aerial	Lena
PSNR	39.5	40.4	40.0	39.2	40.2
Image	Mandrill	Peppers	River	Woman	
PSNR	39.6	40.3	40.0	40.4	

We printed the watermarked images using two different HP printers (HP8000DN and HP Laserjet 4100) and scanned the printed images using HP scanner (HP Scanjet 4570C) and Canon scanner (CanoScan 9900F). The printing resolution is set to 300 and 600 dpi (Dots Per Inch) and Scanning resolution is also 300 and 600 dpi.

Each watermarked image is printed 5 times on each printer and each printed image is then scanned 10 times on each scanner. So for every watermarked image, we obtained total 200 samples. The average bit error ratio (BER) for each image is shown in Fig. 6. Fig. 6 shows that the BERs are all less than 15%. Therefore, we can correctly retrieve the embedded information if we further employ the ECC scheme before watermark embedding [9]. Actually the BERs are also affected by synchronization, especially for our block-based algorithm. Fig. 7 shows the BERs when one image is scanned 10 times on 2 scanners. From Fig. 6 and Fig. 7, we can conclude that the our proposed scheme is robust to PS process.
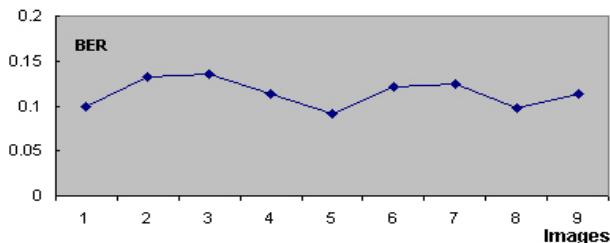

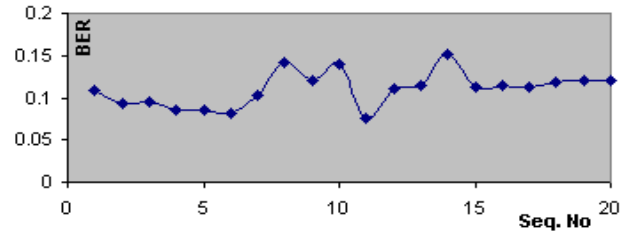**Fig.6** Average BERs of the 9 testing images

Fig. 7 BERs of the image 'Bike" scanned 20 times

5. CONCLUSIONS

In this paper, a novel PS resilient image watermarking scheme is proposed. The image is divided into two types of blocks: smooth block and texture block. Two different watermarking algorithms are detailed for different block types, based on the observed PS properties. Experimental results illustrated that the proposed scheme is robust to PS and has large capacity. Future work includes conducting more rigorous testing with more printers, scanners and test images.

6. REFERENCES

[1] Soo-Chang Pei and Jing-Ming Guo,, "Hybrid pixel-based data hiding and block-based watermarking for error-diffused halftone images", *Circuits and Systems for Video Technology*, IEEE Transactions on, Vol. 13, Issue:8, pp. 867-884, 2003.

[2] Qibin Sun, P. R. Feng and R. Deng, "An optical watermarking solution for authenticating printed documents", *Proceeding of information Technology: Coding and Computing*, pp. 65-70, April, 2001.

[3] J. O'Ruanaidh and T. Pun, "Rotation, Scale, and Translation Invariant Digital Image Watermarking," *Signal Processing*, Vol.66, No. 3, pp. 303-317, 1998

[4] Ching-Yung Lin, Min Wu, Jeffrey A. Bloom, Matt L. Miller, Ingemar Cox, and Yui Man Lui, "Rotation, Scale, and Translation Resilient Public Watermarking for Images", *IEEE Trans. on Image Processing*, May 2001.

[5]Xiaojun Qi and Ji Qi, "Improved affine resistant watermarking by using robust templates", *ICASSP 2004.*, Vol.:3, pp. iii – 495-408, May 2004.

[6] K. Solanki, U. Madhow, B. S. Manjunath, and S. Chandrasekaran, "Estimating and undoing rotation for print-scan resilient data hiding", *ICIP04*, pp.39-42, Oct. 2004.

[7] J. Illingworth and J. Kittler, "A survey of the hough transform," *Comput.Vis., Graph., Image Process.*, vol. 44, pp. 87–116, 1998.

[8] Gonzalez, Rafael C., and Richard E. Woods, "Digital Image Processing". Addison-Wesley Publishing Company, Reading, Massachussetts. 1992.

[9]Dajun He, Qibin Sun and Qi Tian, "A secure and robust object-based video authentication system", *EURASIP J. on Applied Signal Processing, Special issue on Multimedia Security and Right Management,* Nov, pp. 2185-2200, 2004

[10] Wen-Nung Lie and Li Chun Chang, "Data hiding in images with adaptive numbers of least significant bits based on the human visual system", ICIP99. Vol.: 1, pp.286 – 290, 1999