A NEW ROBUST REFERENCE WATERMARKING FRAMEWORK IN GYRATOR DOMAIN

Gaurav Bhatnagar† *and Q.M. Jonathan Wu*‡

Dept. of Electrical and Computer Engineering,
University of Windsor, Windsor-N9B 3P4, ON, Canada.

ABSTRACT

In this paper, a novel reference watermarking scheme based on Gyrator transform is presented. The core idea is to segment original image into non-overlapping blocks using zigzag scan followed by the reference image formation considering the spatial frequency of the blocks. Reference image is then transformed in the Gyrator domain. The embedding of the watermark is done by modifying singular values of reference image in Gyrator domain with the singular values of watermark image. The experimental results demonstrates the performance and robustness of the proposed algorithm against a variety of attacks.

***Index Terms*—** Digital Watermarking, Gyrator Transform (GT), Singular Value Decomposition (SVD), Spatial Frequency, ZIG-ZAG scan.

1. INTRODUCTION

Nowadays, some very crucial issues of digital media are duplication, distribution, editing, copyright protection etc. The main reason of these kind of issues is development of internet and multimedia technology. As a solution, Digital Watermarking is used very frequently [1, 2]. Hence, digital watermarking becomes very attractive research topic and many watermarking scheme have been proposed such as spread spectrum [2], DCT [3], DWT [4], SVD [5–8] and so on.

This paper proposes a new reference watermarking scheme using GT and SVD. First, the original image is segmented into small blocks via ZIG-ZAG sequence then the spatial frequency of all blocks are computed. Then a reference image is obtained by selecting and arranging blocks based on a threshold spatial frequency. This reference image is used for embedding as well as for extraction. The only condition on reference image is that the size is same as the size of watermark. First, reference image is transformed into Gyrator transform domain and then SVD is applied on both the reference and watermark images followed by embedding in the reference image by modifying the singular values using the singular values of watermark. After embedding, the modified reference image is again segmented into blocks and then mapped to their original positions to construct the watermarked image. For extraction, the watermarked reference image is constructed by the watermarked image using the positions of the selected blocks and the reverse process is used for extracting the singular values of the watermark from watermarked reference image.

The rest of the paper is organized as follows. The GT, SVD and spatial frequency are explained in sections 2, 3 and 4 respectively. In section 5, proposed embedding and extraction algorithms are explained followed by the experimental results in section 6. Finally, the concluding remarks are given in section 7.

2. THE GYRATOR TRANSFORM

The Gyrator transform (GT) is a linear integral transform which produces the rotation in the twisted position-spatial frequency planes of phase space [9, 10]. Mathematically, the GT of a 2D real signal $f(x, y)$ with parameter α is defined as

$$\mathcal{G}^{\alpha}[f(x,y)](u,v) = \frac{1}{|\sin\alpha|}\iint f(x,y)K_{\alpha}(x,y,u,v)dxdy \tag{1}$$

where $K_{\alpha}(x, y, u, v)$ is the transform kernel and is given by.

$$K_{\alpha}(t,x) = \exp\left(i2\pi\frac{(uv+xy)\cos\alpha - (uy+xv)}{\sin\alpha}\right) \tag{2}$$

where α is the transform order with (x, y) as input plane and (u, v) as output plane. In order to reconstruct original signal from the transformed signal, the inverse GT corresponds to the GT at rotation angle '-α'. For $\alpha = 0$, it corresponds to the identity transform i.e. the output is the signal itself. For $\alpha = \pi/2$, it reduces to the direct/inverse Fourier transform with rotation of the coordinate at $\pi/2$. For other values of transform order (α), the kernel of GT ($K_{\alpha}(x, y, u, v)$) has constant amplitude and a hyperbolic phase structure. The GT is similar to the fractional Fourier transform (FrFT) but they do not coincide since the kernel of the FrFT is a product of the spherical and plane waves whereas the kernel of the GT is a product of hyperbolic and plane waves [10].

3. SINGULAR VALUE DECOMPOSITION

Let A be a general real(complex) matrix of order $m' \times n'$. The singular value decomposition (SVD) of A is the factorization

$$A = U * S * V^T \tag{3}$$

where U and V are *orthogonal(unitary)* and $S = diag(\sigma_1, \sigma_2, ..., \sigma_r)$, where $\sigma_i, i = 1(1)r$ are the singular values of the matrix A with $r = min(m', n')$, satisfying $\sigma_1 \geq \sigma_2 \geq ... \geq \sigma_r$.

The work is supported by the Canada Research Chair program, the NSERC Discovery Grant. Email: {goravb†, jwu‡}@uwindsor.ca

CCECE 2011 Niagara Falls, Canada
978-1-4244-9789-8/11/$26

The first r columns of V are the *right singular vectors* and the first r columns of U are the *left singular vectors*.

Use of SVD in digital image processing has some advantages. First, the size of the matrices from SVD transformation is not fixed. It can be a square or a rectangle. Secondly, singular values in a digital image are less affected if general image processing is performed.

4. SPATIAL FREQUENCY

Spatial Frequency measures the overall activity level in an image [11, 12]. For an image block I_1 of size $M_1 \times N_1$, the spatial frequency is defined as:

$$SF = \sqrt{RF^2 + CF^2} \quad (4)$$

where RF and CF are the row and column frequencies and are defined as.

$$RF = \sqrt{\frac{1}{M_1 N_1} \sum_{m=1}^{M_1} \sum_{n=2}^{N_1} [I(m,n) - I(m,n-1)]^2} \quad (5)$$

$$CF = \sqrt{\frac{1}{M_1 N_1} \sum_{n=1}^{N_1} \sum_{m=2}^{M_1} [I(m,n) - I(m-1,n)]^2} \quad (6)$$

Now, we will see how spatial frequency varies with respect to the noise. First, the image blocks with size 32×32 of Pirate and Lady images are taken. Then $P\%$ additive and multiplicative Gaussian noise is added to the blocks followed by the spatial frequency calculation. In figure 1, the spatial frequencies are given for degraded versions. After observing the figure, one can easily conclude that if the noise is added in the image then the spatial frequency increases. Hence, if the spatial frequency of an image block is minimum then the presence of the noise will be less in that image block.

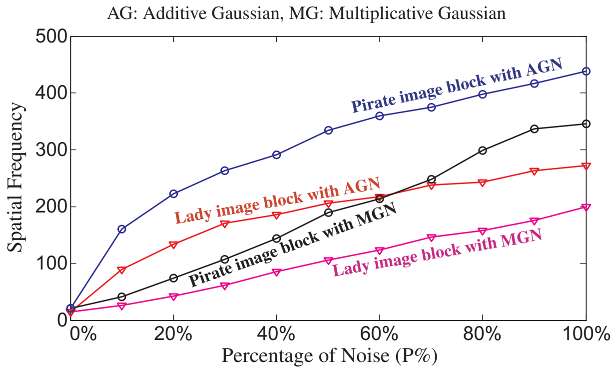


Fig. 1. Spatial Frequency of Degraded Image Blocks.

5. PROPOSED WATERMARKING SCHEME

In this section, we have discussed some motivating factors in design of our approach to reference watermarking. We have used GT and SVD for developing the algorithm. The host and watermark images are gray scale images of size $M \times N$ and $m \times n$ respectively, which are denoted by F and W. The proposed watermarking scheme is illustrated as follows.

5.1. Watermark Embedding

The embedding process is given as follows.

1. First host image is segmented into blocks of size $p_1 \times p_2$ using ZIG-ZAG sequence, denoted by F^l, where l is the number of blocks. With out loss of generality, we can say p_1 and p_2 are the multiples and very less quantity in comparison with M and N.
2. Find out the spatial frequency of all blocks, denoted by SF_{F^l}.
3. Significant blocks are found out based on their spatial frequency. Spatial frequency of each block are sorted in descending order. The threshold spatial frequency is given by
$$T = S\left(\frac{m}{p_1} * \frac{n}{p_2}\right) \quad (7)$$
where $S(\circ)$ is the sorted spatial frequency of the blocks. Those blocks, which have spatial frequency less than or equal to T, are considered as significant blocks and are used for making reference image.
4. Using the significant blocks, construct a reference image F_{ref}, which is of size $m \times n$ and perform GT on the reference image, which is denoted by f_{ref}.
5. Perform SVD transform on both f_{ref} and watermark image
$$f_{ref} = U_{f_{ref}} S_{f_{ref}} V^T_{f_{ref}}, \quad W = U_W S_W V^T_W \quad (8)$$
6. Modify the singular values of reference image with the singular values of the watermark as
$$(\sigma_{f_{ref}})^* = \sigma_{f_{ref}} + \beta\, \sigma_W \quad (9)$$
where β gives the watermark strength.
7. Perform inverse SVD, $f^*_{ref} = U_{f_{ref}} S^*_{f_{ref}} V^T_{f_{ref}}$
8. Perform inverse GT to construct the modified reference image, denoted by f^*_{ref}. Again f^*_{ref} is segmented into blocks of size $p_1 \times p_2$ and mapped onto their original positions for constructing the watermarked image.

We save the positions of the significant blocks and reference image for the extraction process.

5.2. Watermark Extraction

The objective of the watermark extraction is to obtain the estimate of the watermark. For watermark extraction, original reference and watermarked images, left and right singular vectors must be available at the receiver end. The extraction process is given as follows:

1. Using the positions of significant blocks, make the reference image from the watermarked image, denoted by F^W_{ref}.
2. Perform GT on both F^W_{ref} and original reference image, which is denoted by f^W_{ref} and f_{ref} respectively.
3. Perform SVD transform on both f_{ref} and f^W_{ref},
$$f_{ref} = U_{f_{ref}} S_{f_{ref}} V^T_{f_{ref}} \quad (10)$$
$$f^W_{ref} = U_{f^W_{ref}} S_{f^W_{ref}} V^T_{f^W_{ref}} \quad (11)$$

4. Extract the singular values of the watermark,

$$\sigma_W^{ext} = \frac{\sigma_{f_{ref}^W} - \sigma_{f_{ref}}}{\beta} \tag{12}$$

5. Obtain the extracted watermark as:

$$W^{ext} = U_W \, S_W^{ext} \, V_W^T \tag{13}$$

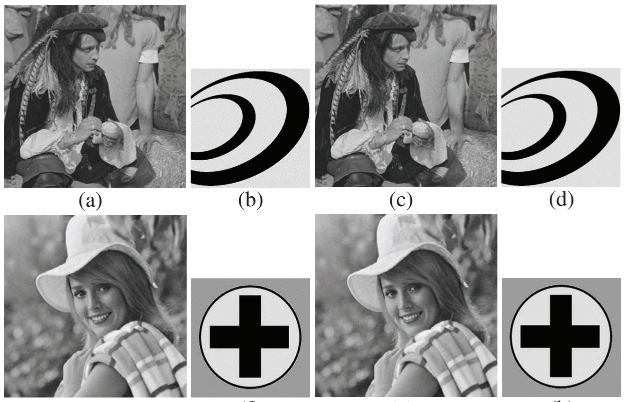
6. EXPERIMENTAL RESULTS

The performance of the proposed watermarking algorithm is demonstrated using MATLAB platform considering Pirate and Lady images as the host images which are of size 512×512. For watermark, two gray scale logos namely Circle and Plus images of size 256×256 are used which are depicted in figures 2(b,f) respectively. Circle logo is embedded into Pirate image while Plus logo is embedded into Lady image. In the experiments, the size of blocks is considered to be 16×16 in order to obtain reference image. The robustness of the proposed algorithm is investigated by considering different kind of attacks such as Gaussian blurring, Gaussian noise addition, JPEG compression, resizing, rotation, cropping, histogram equalization, sharpening and contrast adjustment attacks. After these attacks on the watermarked image, the watermark image is extracted and is compared with the original one. The watermarked image quality is measured using PSNR (Peak Signal to Noise Ratio). The watermarked Pirate and Lady images are having PSNR value of 47.2598 and 45.6987 respectively. There is no perceptual degradation between original and watermarked images according to human visual system. Therefore, the proposed algorithm is perceptually robust. For visual assessment, the host, original watermark, watermarked and extracted watermark images are depicted in figure 2. To verify the presence of the watermark, the correlation coefficient between the original and extracted watermark is acted as the quality measure and is given by

$$\rho(w, \overline{w}) = \frac{\sum_{i,j}(w - \mu_w)(\overline{w} - \mu_{\overline{w}})}{\sqrt{\sum_{i,j}(w - \mu_w)^2}\sqrt{\sum_{i,j}(\overline{w} - \mu_{\overline{w}})^2}} \tag{14}$$

where w, $\overline{w}$, μ_w and $\mu_{\overline{w}}$ are the original watermark, extracted watermark and their respective mean. Due to the page restrictions, the visual results are given for Pirate image (since it has maximum PSNR) whereas correlation coefficients are given for both the images which are given in table 1.

The most common manipulation in digital image is blurring. Watermark is extracted after applying 9×9 Gaussian blurring and the respective results are depicted in figure 3(i). To verify the robustness of the watermarking scheme, another measure is Noise addition. In real life, the degradation and distortion of the image come from noise addition. In the experiments, $P\%$ of additive Gaussian noise is added in the watermarked image. Figure 3(ii) shows the extracted watermark from 50% attacked watermarked images. In real life applications, storage and transmission of digital data, a lossy coding operation is often performed on the data to reduce the



(a) (b) (c) (d) (e) (f) (g) (h)

Fig. 2. a,e) Host b,f) Original Watermark c,g) Watermarked d,h) Extracted Watermark Images.

Table 1. Correlation Coefficients for extracted watermarks after all attacks.

	ρ	
Attacks	Pirate	Lady
No Attack	1.0000	0.9999
Gaussian Blurring (9×9)	0.9078	0.9027
Additive Gaussian Noise (50%)	0.7865	0.7572
JPEG Compression (100:1)	0.9874	0.984
Resizing ($512 \rightarrow 128 \rightarrow 512$)	0.9631	0.9576
Rotation($30°$)	0.4569	0.4505
Cropping(50% area remaining)	0.3159	0.3112
Histogram Equalization	0.9950	0.9965
Sharpening (+90%)	0.9771	0.9757
Contrast Adjustment (-90%)	0.4155	0.4093

memory and increase efficiency. Therefore, the proposed algorithm is also tested for the JPEG compression (100:1) and the results is given in figure 3(iii). The proposed algorithm is also tested for some geometric attacks like resizing, rotation and cropping. For resizing, first the size of watermarked image is reduced to 128×128 followed by the up-sizing to its original size 512×512 and the result is given in figure 3(iv). The results for 30° rotation is depicted in figure 3(v) whereas the result when only 50% area remaining of watermarked image is shown in figure 3(vi). Further, the proposed algorithm is tested for some image processing attacks like Histogram Equalization, Sharpening and Contrast Adjustment and the respective results are shown in figures 3(vii–ix) respectively. For sharpening attack, the sharpness of the watermarked image is increased whereas for contrast adjustment contrast is reduced by 90%.

7. CONCLUSIONS

In this paper, a new robust reference watermarking scheme based on GT, spatial frequency and SVD is presented where the watermark is a visually meaningful gray scale image instead of a noise type Gaussian sequence. The benefit of segmentation into the non-overlapping blocks using ZIG-ZAG sequence is to choose pixel in each block arbitrarily followed by the blocks selection based on spatial frequency which gives the overall activity level of the blocks. The main attraction of the proposed algorithm is the use of GT and reference image. Since, none can extract the watermark without the exact knowledge of the transform order and reference image. Therefore, the security of the proposed method lies in the reference image and transform order of GT. Finally, a brief investigation is done in order to show the robustness of the proposed algorithm by a variety of attacks.

8. REFERENCES

[1] N. F. Johnson, Z. Duric and S. Jajodia, *Information Hiding: Steganography and Watermarking Attacks and Countermeasures*, Springer, 2000.

[2] I.J. Cox, M.L. Miller and J.A. Bloom, *Digital watermarking*, Morgan Kaufmann, 2001.

[3] G. Langelaar, I. Setyawan and R.L. Lagendijk, "Watermarking Digital Image and Video Data," *IEEE Signal Processing Magazine*, vol 17, pp. 20–43, 2000.

[4] P. Meerwald and A. Uhl, "A survey on wavelet domain watermarking algorithms," *Proc. of SPIE, Electronic Imaging, Security and Watermarking of Multimedia Contents III*, vol. 4314, CA, USA, pp. 505–516, 2001.

[5] R. Liu and T. Tan, "An SVD-Based Watermarking Scheme for Protecting Rightful Ownership," *IEEE Transactions on Multimedia*, vol. 4, no. 1, pp. 121–128, 2002.

[6] E. Ganic and A.M. Eskicioglu, "Robust Embedding of Visual Watermarks Using DWT-SVD," *Journal of Electronic Imaging*, vol. 14, no. 4, 2005.

[7] Gaurav Bhatnagar and Balasubramanian Raman, "A new robust reference watermarking scheme based on DWT-SVD," *Computer Standards & Interfaces*, vol. 31, no. 5, pp. 1002–1013, 2009.

[8] Gaurav Bhatnagar and Balasubramanian Raman, "Robust Reference-Watermarking Scheme Using Wavelet Packet Transform and Bidiagonal-Singular Value Decomposition," *Int. J. Image Graphics*, vol. 9, no. 3, pp. 449–477, 2009.

[9] J.A. Rodrigo, T. Alieva and M. L. Calvo, "Gyrator transform: properties and applications," *Opt. Express*, vol. 15, pp. 2190–2203, 2007.

[10] J.A. Rodrigo, T. Alieva and M.L. Calvo, "Experimental implementation of the gyrator transform," *J. Opt. Soc. Am. A*, vol. 24, no. 10, pp. 3135–3139, 2007.

[11] Eskicioglu, A.M., Fisher, P.S.: Image quantity measures and their performance. *IEEE Transcation on Communication*, vol. 43, no. 12, pp. 2959–2965, 1995.

[12] S. Li, J.T. Kwok and Y. Wang, "Combination of images with diverse focuses using the spatial frequency," *Information Fusion*, vol. 2, pp. 169–176, 2001.

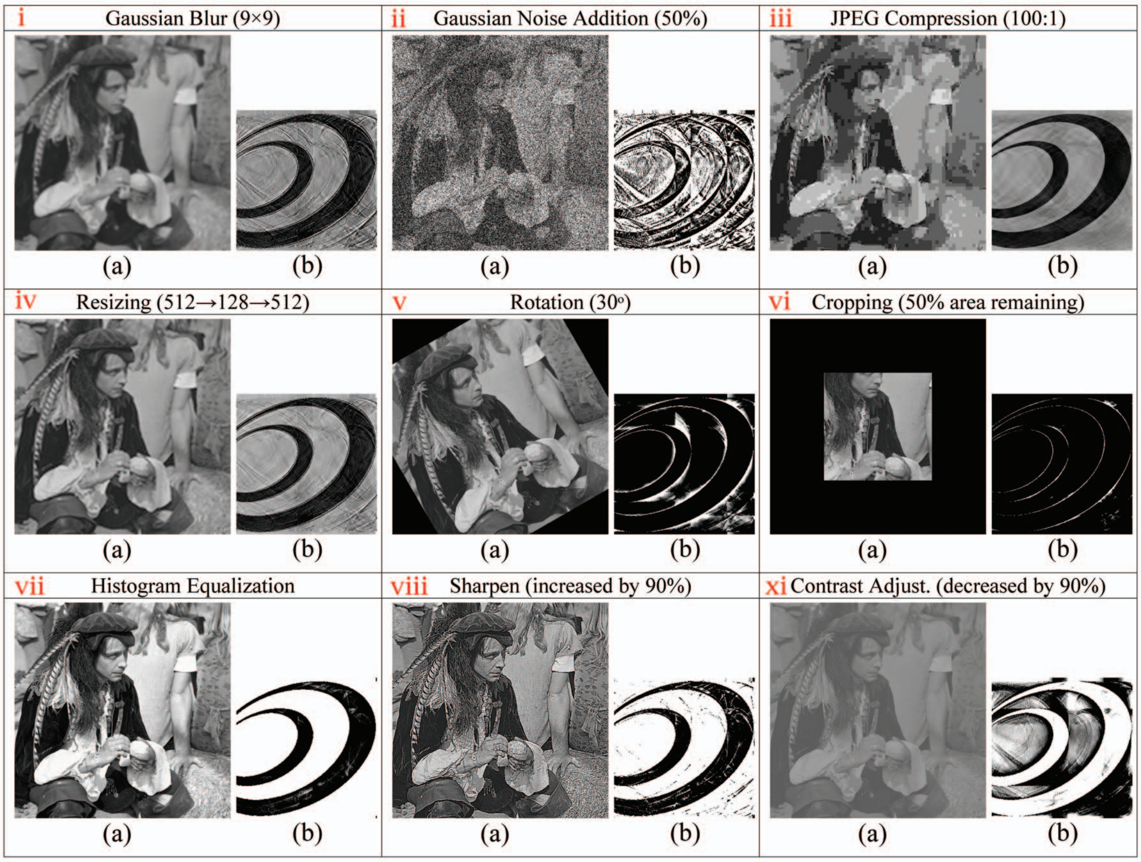


Fig. 3. a) Attacked watermarked b) extracted watermark images after different kind of attacks.