RST Invariant Digital Watermarking Based on Image Representation by Wedges and Rings

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ABSTRACT

This paper describes a new image watermarking scheme invariant to rotation, scaling and translation (RST) attacks. For obtaining the invariance properties we propose to present an image of watermark by wedges and rings to convert its rotation to shift and then utilize the shift invariance property of the Direct Fourier Transform (DFT). But in contrast to conversional schemes based on the Fourier-Mellin transform (FMT), we do not use a log-polar mapping (LPM). As a result, our scheme preserves high quality of original image since it is not underwent to LPM. For withstanding against JPEG compression, noise addition and low-pass (LP) filtering attacks a low frequency watermark is embedded into middle frequencies of the original image. Experiments with various attacks show the robustness of the proposed scheme.

Keywords: *Copyright protection, image watermarking, geometric attacks.*

1. INTRODUCTION

An important property of any watermarking scheme is its robustness with respect to image distortions. This means that the watermark should be readable from images that undergo such common attacks as rotation, scaling, translation, cropping, JPEG compression, addition of noise, low-pass filtering. While many schemes perform well against compression, LP filtering and others, they lack robustness to RST attacks [1]. Generally, RST attacks are thought of as one of the most dangerous attacks in the digital watermarking world.

Several watermarking schemes resistant to RST attacks have been presented in resent years. These may be divided in three main groups. The first group includes watermarking schemes based on deriving a domain that is invariant to RST. In these schemes different modifications of the FMT are used [1], [2].

The second group includes template-based schemes. In these schemes, a template is inserted into a host image in addition to the watermark embedding [3,4]. Other approaches of this group based on the autocorrelation function (ACF) [3].

The third group includes feature-based watermarking schemes which use geometric distortion-invariant features such as edges or corners for watermarking embedding [5], [6].

The study goal of this paper was to design a simple watermarking scheme that was resistant to RST, cropping attack, JPEG compression, and LP filtering. The proposed idea of rotation invariance is similar to the idea of the FMT: convert the rotation in spatial domain to shift, and then utilize the shift invariance property of the DFT to get the rotation invariance. But the implementation is quite different. The FMT is a log-polar mapping followed by the DFT, while an inverse FMT is an inverse log-polar mapping (ILPM) followed by an Inverse Fourier Transform (IFT). In practice the LPM and ILPM make the image quality unacceptable [1]. Really, the problem with this method is that perfect inversion of the FMT is impossible. Thus, interpolation in the Fourier domain is necessary, and the resulting image quality is very poor [3]. In accordance with our scheme we do not transform the original image to any domain and embed the watermark directly into it in the spatial domain. This means that only the watermark image goes through some conversions, not the original image. So in this respect the quality of the original image remains the same. Furthermore, robustness of the schemes based on the FMT transform strongly depends on the degree of rotation of the watermarked image. In the proposed scheme such dependence is absent in principle because we do not use LPM and ILPM.

The idea of scale invariance is quite different from the idea of the FMT and is based on a new image representation. The resistance of the proposed scheme to JPEG compression and LP filtering was achieved by embedding a watermark into the host image in the middle frequencies.

2. IMAGE REPRESENTATION

We describe an image by areas ΔS_{mn} obtained as a result of intersections of M wedges and N rings as shown in figure 1. Then a mean gray level g_{mn} of the area ΔS_{mn} , which is the

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intersection of the $m\,th$ wedge and the $n\,th$ ring can be expressed as:

$$g_{mn}=\frac{1}{K^{mn}}\sum_{k=1}^{K^{mn}}p_k^{mn} .$$

Here p_k^{mn} is the gray level of the $k\,th$ pixel within the area ΔS_{mn} and K^{mn} is the total number of pixels within this area.

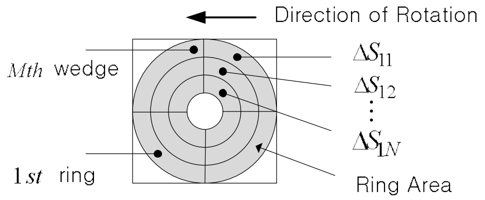


Fig. 1 Image representation by intersections of M wedges and N rings where $m=\overline{1,M}$, $n=\overline{1,N}$

The image is represented by the matrix Γ :

$$\Gamma=\begin{bmatrix} g_{11} & g_{12} & \cdots & g_{1N} \\ g_{21} & g_{22} & \cdots & g_{2N} \\ \vdots & \vdots & \ddots & \vdots \\ g_{M1} & g_{M2} & \cdots & g_{MN} \end{bmatrix} .$$

A rotation of the original image results in a parallel and cyclical shifting of the matrix elements:

$$\ddot{\Gamma}=\begin{bmatrix} g_{21} & g_{22} & \cdots & g_{2N} \\ \vdots & \vdots & \ddots & \vdots \\ g_{M1} & g_{M2} & \cdots & g_{MN} \\ g_{11} & g_{12} & \cdots & g_{1N} \end{bmatrix}.$$

It implies that the rotation causes the elements of matrix Γ to "wrap around". In this case the rotation invariance may be reached by utilizing the shift invariance property of the DFT

$$G_{uv}=\frac{1}{MN}\sum_{m=1}^{M}\sum_{n=1}^{N}g_{mn}\exp\left[-i\,2\pi\left(\frac{mu}{M}+\frac{nv}{N}\right)\right] .$$

Furthermore, if the image scale is reduced or enlarged in such a way that the number of rings and wedges remains the same, then the size of the matrix Γ will not change. This means that the proposed representation of the image is also invariant to scale.

3. PROPOSED PRINCIPLES OF WATERMARK EMBEDDING AND EXTRACTION

To simplify a problem let us consider one-dimensional case. Suppose that a L-F watermark is given by a simple binary sequence $w(m)$ of length $M=2^n\,(n=1,2,...)$ with mean zero and unit variance as shown in figure 2.

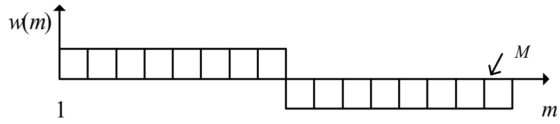


Fig. 2 The sequence of a low frequency watermark when $M=16$

In accordance with our approach we propose to present the sequence $w(m)$ by a succession of elementary bipolar subsequences. For practical realization of this decomposition we first propose to generate a piece-wise sequence $f(m)$ of length M which is divided into K subsequences, where $K=2^d$, $d=\overline{1,n-1}$. In this case each subsequence will consist of 2^{n-d} samples and may be presented as follows (see Fig. 5a):

$$s(g)=\begin{cases} 1, & g=\overline{1,2^{n-d-1}} \\ -1, & g=\overline{2^{n-d-1}+1,2^{n-d}} \end{cases}$$

where g is the current number of a sample within the subsequence. Then the sequence $f(m)$ can be defined as $f(m)=s(\hat{g})$ where $\hat{g}$ is calculated as the division residue of m by 2^{n-d}.

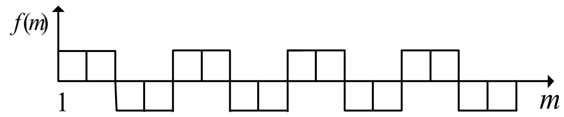


Fig. 3 The piece-wise sequence $f(m)$ when $M=16$ and $K=4$

Then we modulate the sequence $f(m)$ with the help of L-F sequence $w(m)$ by finding their multiplication $\hat{w}(m)=w(m)\times f(m)$. As a result the sequence $\hat{w}(m)$ is formed consisting of elementary bipolar subsequences $s(g)$ or $(-s(g))$.

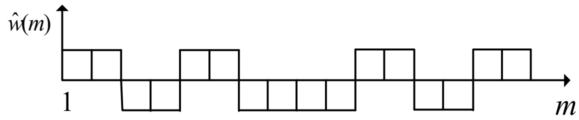


Fig. 4 The piece-wise sequence $\hat{w}(m)$

In general case the sequence $\hat{w}(m)$ may be described as

$$\hat{w}(m)=\pm s(\hat{g}) .$$

Now suppose that it is necessary to embed the elementary bipolar subsequence $s(g)$ into the host subsequence $h(m)$ presented in figure 5(b). This procedure can be done by linear combination of the subsequence $s(g)$ with the host subsequence $h(m)$

$$\hat{s}(m) = h(m) + \alpha\, s(m)$$

where α represents a scaling factor.

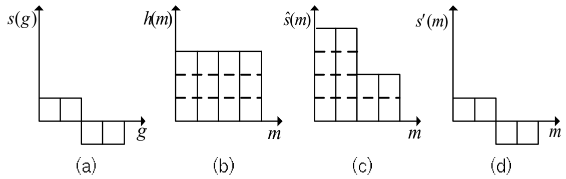


Fig. 5 The elementary bipolar subsequence $s(g)$, the host subsequence $h(m)$, the watermarked subsequence $\hat{s}(m)$ when $\alpha = 1$ and the extracted watermark subsequence $s'(m)$

So we obtain the watermarked subsequence $\hat{s}(m)$ shown in figure 5©. The extraction procedure can be done by centering the subsequence $\hat{s}(m)$. The composition of the sequence $w(m)$ from elementary subsequences is fulfilled by multiplication procedure

$$w(m) = \hat{w}(m) \times f(m) \qquad (1)$$

One of our goals is to embed a watermark that is resilient to JPEG compression and LP filtering. To achieve this goal we propose to embed a watermark into the host image in the middle frequencies. Note that the sequence $f(m)$ may be considered as a frequency carrier (FC) for the low-frequency watermark $w(m)$.

4. ALIGNMENT PROCEDURE, WATERMARK EMBEDDING AND EXTRACTION

The purpose of this procedure is to create equal conditions for embedding the subsequences $s(g)$. Let, for example, the subsequence $s(g)$ must be embedded into the host subsequence shown in figure 6.

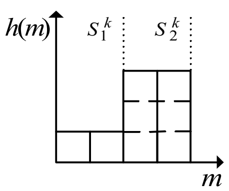


Fig. 6 The host subsequence $h(m)$ presented by two different gray levels

It is apparent that after such embedding it will be nothing to extract. So before the embedding we propose to modify the host sequence as follows. First we devide the whole sequence $h(m)$ into two equal subintervals and calculate the mean gray levels of the left and right subintervals S_1^k and S_2^k where $k = \overline{1, K}$. Then we propose to align this sequence under the condition of the following of equality

$$S_1^k = S_2^k .$$

This means that in general case the values S_1^k and S_2^k must be changed in order to align their mean levels. With this goal we first calculate the difference between the mean gray levels of the k th subinterval

$$a = S_1^k - S_2^k \qquad (2)$$

and then produce the alignment

$$S_1^k := S_1^k - a \text{ and } S_2^k := S_2^k + a \qquad (3)$$

4.1. Block-diagrams of Watermark Embedding

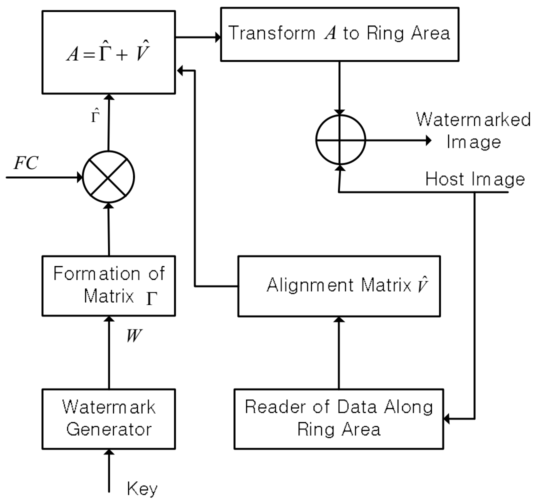


Fig. 7 Block-diagram of a watermark embedding

The block diagram of the embedding scheme is shown in figure 7. As this figure shows, for reaching dimension matching between the watermark and the ring area we first transmit the watermark into an intermediate matrix Γ of $M \times N$ size the rows and columns of which correspond to wedges and rings of the ring area, respectively. In order to present the watermark W by a succession of elementary bipolar subsequences we modulate the FC with the values of the matrix Γ and obtain matrix $\hat{\Gamma}$ containing these bipolar subsequences. For producing equal conditions for their embedding we concurrently read out the gray level values of the host image along the ring area and put them down to the matrix V of the same size as the matrix Γ . Then on the base of (2) and (3), the alignment matrix $\hat{V}$ is formed, which is used for correction the embedding data. For this goal we create the correction matrix A by finding summation of the two matrices $\hat{\Gamma}$ and $\hat{V}$. On the final stage a value of each element of the matrix A is assigned to each pixel within ΔS_{mn} area. Note that size of ΔS_{mn} is chosen under condition that the watermark could be inserted into the host image in middle frequencies.

The watermarked image is obtained as a result of summing the host image and the watermark converted to ring area. with the gain factor α and the alignment The advantage of the proposed scheme is that it takes into account the local gray differences between neighboring sequences of pixels of the host image. and uses information to create equal conditions for embedding because α is a constant.

4.2. Block-diagram of Watermark Extraction

One of the main goals of the extraction procedure is to obtain matrix $\hat{\Gamma}$, which would be analogous to the matrix Γ. To achieve this, a center of the given ring area of the potentially attacked image is first found and the gray level values of the ring area are put down into a matrix $\dot{\Gamma}$ of $M \times N$ size (see Fig. 8). Then the values of the matrix $\dot{\Gamma}$ are centered to detect the elementary binary subsequences and on the base of (1) the matrix $\ddot{\Gamma}$ is formed, which in general is analogous to the original matrix Γ. However, as a result of the image possible rotation, the values of the matrix $\ddot{\Gamma}$ may be shifted along its columns relatively columns of the matrix Γ. This means that we can not directly compare two matrices Γ and $\ddot{\Gamma}$ on similarity. To prevent this shifting, it is proposed to transform the values of the matrix $\ddot{\Gamma}$ into frequency domain and then back to the space domain using the phase spectrum corresponding to the original position of the matrix Γ.

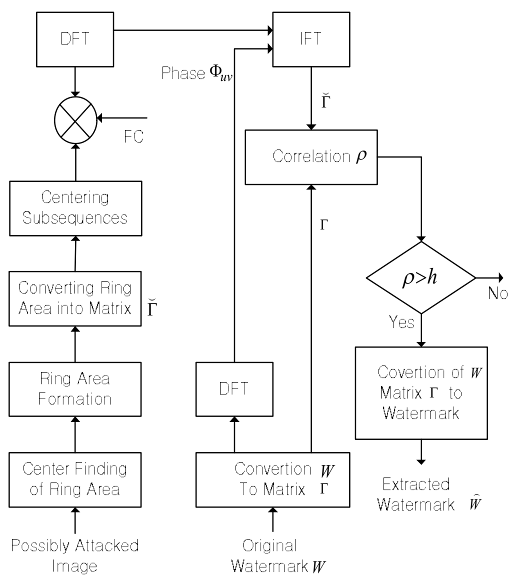


Fig. 8 Block-diagram of a watermark detection and extraction

To make a decision, the correlation $\rho(\Gamma,\hat{\Gamma})$ is calculated and compared to the threshold h. If $\rho > h$, a watermark is detected and the procedure of the watermark extraction is fulfilled by transforming the matrix $\hat{\Gamma}$ into the watermark image. Note that to increase the quality of making decision the other criteria may be applied, for example, such as Bayes' criterion.

The phase Φ_{uv} may be considered as an additional secret key and its using increases the intercept security of the watermarking scheme. If one has not this matrix at his disposal then he can not detect and extract the watermark. It is necessary to stress that even in the case when an attacker has an image of the watermark, still he can not obtain the phase Φ_{uv} if he does not know the procedure of its forming.

5. EXPERIMENTAL RESULTS

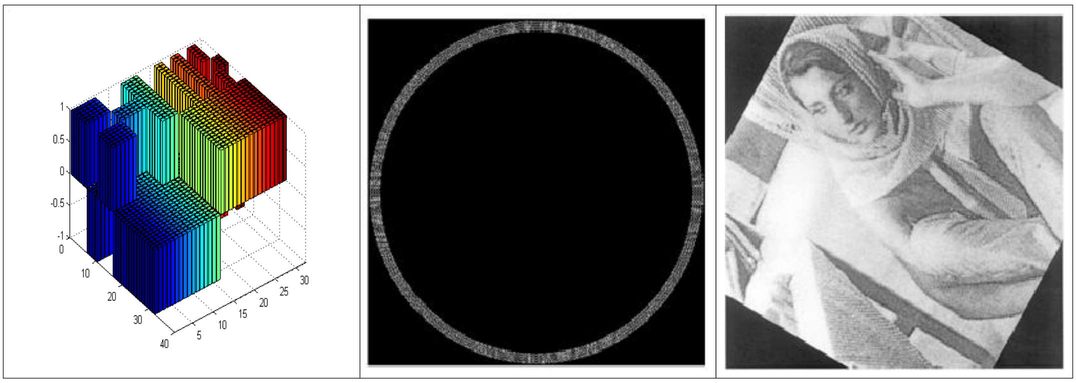
The experiments were performed using standard test images such as "Barbara" and "Lena" with 512×512 pixels and 256 grey levels, respectively. Ten low-frequency watermarks of different configuration and the same size (32×32) were used during experiments. One of them is shown in Fig.9a. Each watermark was converted into the matrix Γ consisting of 256 rows and 4columns.

The watermark presented in a form of the ring area is shown in figure 9b. Figure 9c shows the watermarked image of "Barbara" rotated at a 60^o angle. The correlations ρ and $\hat{\rho}$ are given in Table 1, respectively for the proposed scheme and that in [1]. As it is seen from 9 we rotated the image with cropping as it was implemented in paper [1] (see Fig. 9a in paper [1]).

Table 1. Rotation, scale and JPEG Attacks

Angle	0^o	0.5^o	10^o	30^o	45^o	60^o	90^o
	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
$\hat{\rho}$	0.9860	0.8219	0.8508	0.7873	0.7078	0.6451	0.8626
Scale	0.5	0.6	0.7	0.8	0.9	1.1	1.2
ρ	0.9017	0.9015	0.9357	0.9373	0.9609	0.9611	0.9605
$\hat{\rho}$	-	0.7834	0.8335	0.8469	0.8839	0.9013	0.8401
JPEG	5 %	10 %	20 %	30 %	40 %	50 %	60 %
ρ	0	0.9011	0.9013	0.9013	0.9369	0.9371	0.9472
$\hat{\rho}$	0.3189	0.7561	0.8579	0.9394	0.9605	0.9681	0.9766

The Table 1 shows that under the same conditions (rotation with cropping) we have better results that are presented in paper [1]. In contrast with the scheme presented in paper [1] it is apparent that in our case cropping outside the ring area does not exert any influence on the robustness of the scheme. It is seen that the correlation ρ does not depend upon the image rotation. Note that in case of using the FMT [1, part of Table 1] the values of the correlation $\hat{\rho}$ greatly depend upon the angular position of an image (see in Table 1).



(a) (b) (c)

Fig. 9 Watermark embedding (a) Original watermark, (b) Watermark converted to a form of the ring area, (c) Watermarked image of "Barbara" rotated at a 60^{o} angle

Table 2. Different Kinds of Attacks

ATTACK	ρ	$\hat{\rho}$
Gaussian White noise N(0, 0.001)	0.9557	0.9399
Gaussian White noise N(0, 0.005)	0.9135	0.8748
Gaussian White noise N(0, 0.01)	0.8731	0.6760
Gaussian filter: filter size [7 x 7], standard deviation 0.5	0.9583	0.9659
Gaussian filter: filter size [7 x 7], standard deviation 1	0.9514	0.9507
Gaussian filter: filter size [3 x 3], standard deviation 1	0.9552	0.9605
Gaussian noise pollution: N(0, 0.001) Wiener Filter to remove noise	0.9236	0.9101
Salt and pepper pollution: noise density 0.001 Median Filter to remove noise	0.9013	0.8887

In scaling experiments, the scale of the analysed image was changed by verifying its resolution. Note that this process may be closely approximated by an L-P filtering operation [4].

The proposed scheme was tested with many kinds of attacks including noise pollution, noise removing operation, filter operation, and an L-P filtering operation. Stermarks was used for generation the distortions. The test results are shown in Table 2, from which we can see that correlation coefficients for the proposed scheme are not lesser than given in paper [1] (see Table VI in paper [1]). The scheme also displayed a high robustness to mosaic filtering. After image filtering with a 3×3 aperture it was also not less than 0.9014.

However, after filtering with a 4×4 aperture the correlation was equal to zero. Note that the quality of any image becomes definitely unacceptable even after filtering with a 3×3 aperture.

6. CONCLUSIONS

In this paper, a new scheme of an image watermarking, resistant to geometric, JPEG compression, addition of noise and L-P filtering attacks has been demonstrated with simulations yielding valid results. The proposed scheme showed better detection and extraction performance against these attacks than the scheme based on the FMT.

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