Invariant Digital Image Watermarking Scheme in the Projected-Frequency Domain

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Abstract. The development of Internet and computer technologies facilitates the data processing and transmission but also they make the data vulnerable to hacking and illegal modification. In fact, the development of an effective way for data protection represents an important research focus. For this reason, three techniques for data security are proposed, which are: cryptography, steganography and watermarking. In this order, we propose to develop a new blind watermarking approach based on new hybrid decomposition. Our contribution is defined by two steps: The first one is to construct the projected-frequency domain. This domain is described by its invariance face to noises, JPG compression and asynchronous attacks. Also, the transformed image to this field is represented by a larger size and higher coefficients than the original image. Based on these proprieties, we defined our second contribution which consists to develop a blind and robust watermarking scheme in the given field. Simulation results and comparative study prove the robustness and the imperceptibility of the proposed watermarking approach.

Keywords: Discrete Cosine Transform · Digital image watermarking
Discrete radon transform · Imperceptibility · Projected-frequency domain
Robustness

1 Introduction

In recent years, digital image protection technology has made great progress. Several techniques and approaches are proposed for this purpose but the rapid development of technology limits its effectiveness. From 1990, researchers proposed to use the watermarking technique for copyright protection. The proposed algorithms are performed on spatial and transformed domains [1]. Such as, we present the watermarking techniques based on the Discrete Radon Transform (DRT) and Discrete Cosine Transform (DCT).

Based on the DCT transform proprieties, the researchers proposed several watermarking schemes robust to compression attacks [2, 3]. Liu et al. proposed a blind watermarking algorithm based on the Quadratic DCT transform. The watermark is embedded into the high frequency coefficients represented in the DCT blocks [4]. Also, based on the inter-block relation of the crisscross Discrete Cosine Transform (DCT), Hsu and Hu proposed a watermarking scheme where the partly sign-altered mean modulation (PSAM) DCT coefficients is combined with mixed modulation (MM) for use in

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crisscross inter-block prediction [5]. In other work, Guan et al. are proposed, in [2], a new blind digital image watermarking approach based on two-level DCT transform resilient to several common image processing and geometrical attacks. In [3], the authors proposed a blind image watermarking based on differential embedding in Discrete Wavelet Transform (DWT) and DCT domains. Also, Das et al. proposed in [6] a robust and blind watermarking approach based on the DCT transform by using the inter-block coefficient correlation.

Moreover, the Radon transform is used to ensure the robustness of watermarking approach to asynchronous attacks. In this order, Essaidani et al. proposed a robust watermarking approach to synchronous and asynchronous attacks based on the DRT for RGB color images [7]. Similarly, in [8], the authors proposed a watermarking approach for gray scale images based on the DRT. Moreover, Sharmaa et al. proposed a watermarking scheme based on Finite Radon Transforms and Fractional Fourier Transforms. These transforms are applied sequentially to the host cover image. The watermark is embedded by variation of the computed eigenvalues from the singular value decomposition (SVD) of the transformed image by using the eigenvalues corresponding to the SVD of the watermark [9]. Also, Wang et al. proposed a robust image watermarking scheme based on the Generalized Radon Transform (GRT) and Discrete Fourier Transform (DFT). This approach uses the phase information of the DFT as feature of image and the GRT invariance to indentify the geometrical attacks [10]. In order to improve the robustness against rotation, scaling and translation attacks, Zheng et al. proposed an invariant digital image watermarking based on Log-Polar mapping and phase correlation. The watermark is embedded in the LPMs of the Fourier-Mellin magnitude spectrum of an original image [11].

The watermarking approaches based on DCT transform represent a considerable robustness to JPEG compression. Based on these advantages, we propose, in this paper, to combine the DRT and DCT transforms for a projected-frequency host cover image's representation. This representation allows a transformed image with larger size and higher coefficient's values than the original one. Also, it gives an invariant representation face to noises, JPEG compression and asynchronous attacks. Based on these advantages, the transformed image to projected-frequency domain is used to develop a blind, robust and imperceptible digital image watermarking with important embedding capacity. This paper is organized as follows: the next section presents a mathematical background of the DRT and DCT transforms and a representation of the developed domain. The third section describes the proposed watermarking approach. Simulation results and comparative studies to prove the performance of the proposed watermarking scheme are presented in Sect. 4.

2 Projected-Frequency Domain Representation

The basic idea of this transformation is to develop an invariant domain face to geometrical and compression attacks for watermarking scheme. So, the projected-frequency transform is developed to compute the frequencies component of the projected image. In fact, the projected image is computed by using the principle of the DRT transform and the frequency decomposition is obtained by using the principle of DCT algorithm by blocks (8 × 8). The projected-frequency domain is given by using the following algorithm (Fig. 1):

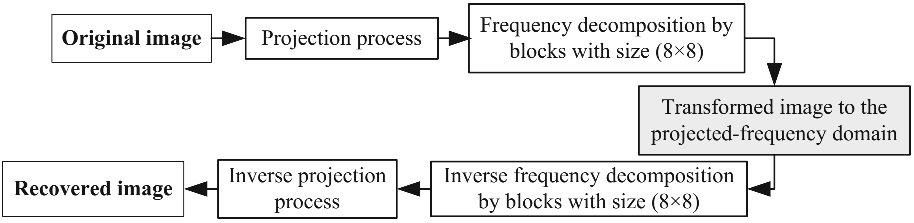


Fig. 1. Image representation in the projected-frequency domain and its inverse transformation

The projected-frequency transform gives a transformed image with size more than the spatial image's size with higher coefficients amplitudes and frequencies repartition (see Fig. 4). These advantages are due to the combined DRT and DCT algorithms. Where the projection process represents the original image with higher values and larger size and the frequency decomposition gives a frequency representation of the projected image.

For these reasons, the transformed image is used to develop a new blind, robust and imperceptible watermarking scheme with important embedding capacity. This approach is given in the next section.

3 Proposed Watermarking Approach

3.1 Watermark Embedding Process

The aim of this approach is to develop an imperceptible, blind and robust watermarking approach based on the invariance characteristics, the larger size and the important coefficient's values of the projected-frequency image. The secure data is embedded in the transformed image by using the following steps:

Step 1: Represent the cover image in the DRT-DCT domain: Firstly, the host cover image I is transformed by the DRT transform. Then, the frequency component of the projected image is computed by using the DCT by blocks (8 × 8). These transformations give the represented image I^{RC} in the projected-frequency domain.

Step 2: **Chose the used coefficients for data embedding:** For more robustness, the more energy region of the transformed image is selected to encode the original watermark W_o with size $(M_w \times N_w)$. This region is correspondent to the more energy region in the transformed image I^{RC}. It contains the important information of the host cover image. This region has the size $(M_r \times N_r)$ which is computed by using the following equation:

$$\begin{cases} M_r = N_r = \frac{L_w}{2} \times 8 & if\ L_w\ is\ even \\ \begin{cases} M_r = \left[E\left(\frac{L_w}{2}\right) + 1\right] \times 8 \\ N_r = E\left(\frac{L_w}{2}\right) \times 8 \end{cases} & else \end{cases} \quad (1)$$

Where $L_w = M_w \times N_w$ represents the number of the embedded bits.
In order to improve the resistance of the proposed watermarking approach to compression attacks and ensure an imperceptible watermarking, the used coefficients to embed the watermark are chosen from the medium frequency band of each transformed block H_i. These coefficients are chosen based on the recommended JPEG table. In fact, these elements present identical quantization values. Consequently, we chose the elements at (2, 3) and (4, 1) positions in each block H_i, noted $h\,(2, 3)$ and $h(4, 1)$, respectively.
Step 3: Embed the data into the chosen coefficients: In order to ensure a blind watermarking approach, we chose the defined embedding method proposed by Eq. 2. The pixel $h\,(2, 3)$ is used to encode the watermark while the pixel $h\,(4, 1)$ is conserved to be a reference for blind data recovering. So, the i^{th} element of the vector W is encoded into the block H_i by using the following relationship:

$$\begin{cases} h_w(2,3) = h\,(4,1) + G\ if\ W(i) = 1 \\ h_w(2,3) = h\,(4,1) - G\ if\ W(i) = 0 \end{cases} \quad (2)$$

Where $1 \leq i \leq L_w$ and G is the used gain factor to embed the watermark. It is used in order to improve the robustness of the proposed approach to several attacks and to reduce the probability of detection error. Nevertheless, the selection of the gain factor must be limited by the imperceptibility constraint of the watermarking approach.
Step 4: Represent the watermarked image in the spatial domain: Finally, the watermarked image is obtained by the Inverse Discrete Cosine Transform (IDCT) by blocks with size (8 × 8) and the Inverse Discrete Radon Transform (IDRT) to the watermarked image. The next subsection describes the watermark recovering process.

3.2 Watermark Recovering Process

In order to recover the embedded data with minimal loss, we must use the same steps, parameters and details which are used in watermark embedding process. Firstly, the watermarked image is transformed to the projected-frequency domain by using the same parameters (angles, radial distance, blocks size…) defined in the embedding process. Then, the watermarked region is selected from the transformed image. The watermarked coefficient $h'(2, 3)$ and $h'(4, 1)$ from each block H_i' with size (8 × 8) are selected. A comparison test between the selected coefficients is performed to decide if the recovered bit is equal to 1 or 0. The recovering test is described by the following equation:

$$\begin{cases} V'(i) = 1 \ \ if \ \ h'(2,3) > h'(4,1) \\ V'(i) = 0 \ \ else \end{cases} \tag{3}$$

Where $1 \leq i \leq L_w$. The recovered vector V' is transformed to a matrix with size $(M_w \times N_w)$ to obtain the recovered watermark.

In order to prove the robustness and the imperceptibility of the proposed watermarking scheme, we present, in the following section, several experimental and comparative studies.

4 Performance Evaluation of the Proposed Watermarking Scheme

4.1 Simulation Results

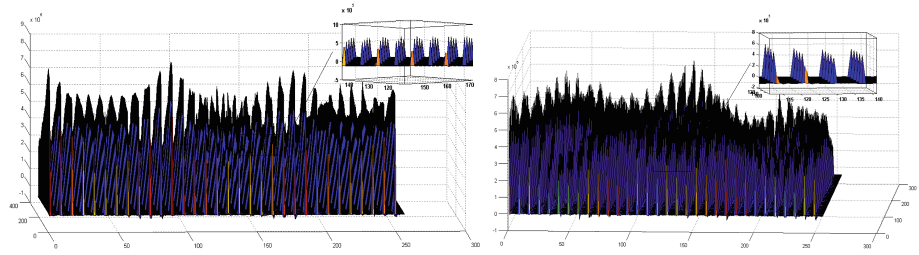
The proposed watermarking approach has been implemented using MATLAB and a database composed by 50 gray scale images and 50 binary watermarks. Figure 2 represents an example of two host cover images with size equal to (512 × 512) and Fig. 3 represents the used binary watermark with size equal to (32 × 32).

Baboon Bridge

Fig. 2. Original cover images

Fig. 3. Original watermark

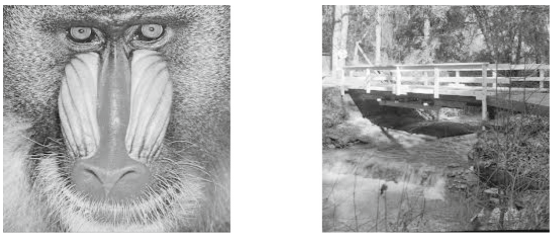
To embed the watermark, the host cover image is transformed to the projected-frequency domain by using a direction factor $\theta_t \in [0, 2\pi]$ with integration path $\Delta\theta = 1°$ and a radial distance $\rho_d \in [0, \sqrt{M^2 + N^2} + 1]$ scaled by the path $\Delta\rho = 1\,pixel$. The higher energy region, with size equal to (256 × 256), is selected from the transformed image to encode the watermark. The selected regions from the Baboon and Bridge host cover images are shown in Fig. 4.



Baboon Bridge

Fig. 4. Selected regions in the projected-frequency domain for data dissimulation

This region is composed by 1024 blocks with size equal to (8 × 8). These blocks are used to embed the watermark. Figure 5 illustrates the different watermarked images in the spatial field.



Baboon Bridge

Fig. 5. Watermarked images

The imperceptibility study, by using the PSNR, between the watermarked and the original cover images gives 44.19 dB for Baboon and 40.26 dB for Bridge. The obtained results prove the considerable imperceptibility of the proposed approach. This property is due to the high values of the generated coefficients by the projected-frequency transform. These coefficients allow the watermark embedding with important gain factor and without degrading the visual quality of the watermarked images in the spatial domain.

In order to study the robustness of the proposed watermarking approach, the watermarked images were attacked by a variety attacks generated by StirMark. The extracted watermark after attacks is compared to the original one by using the normalized correlation (NC) and the Peak Signal to Noise Ratio (PSNR). The following table illustrates the similitude rates between the original watermark and the recovered watermarks after synchronous and asynchronous attacks (Table 1).

Table 1. Simulated rates between original and recovered watermarks after attacks

Attacks	Recovered watermark from Baboon		Recovered watermark from Bridge	
	NC	PSNR	NC	PSNR
JPEG_30	0.95	15.95	0.95	16.12
JPEG_50	0.99	27.09	0.99	24.08
JPEG_60	1	INF	1	INF
Gaussian noise_0.03	1	INF	1	INF
Median filter [5 5]	0.96	16.68	0.96	16.88
Translation_20	1	INF	1	INF
Rotation_10°	1	INF	1	INF
Rotation_90°	1	INF	1	INF
Rotation _0.5°	0.98	22.32	0.98	21.07
Rotation_3°	0.99	30.1	0.99	24.08
Affine_8	1	INF	1	INF
RML_40	1	INF	1	INF
Rotation and scaling_1	1	INF	1	INF
Histogram equalization	1	INF	1	INF

Figure 6 represents some of the watermarked and attacked images with StirMark attacks while Fig. 7 illustrates the recovered watermarks from these images.

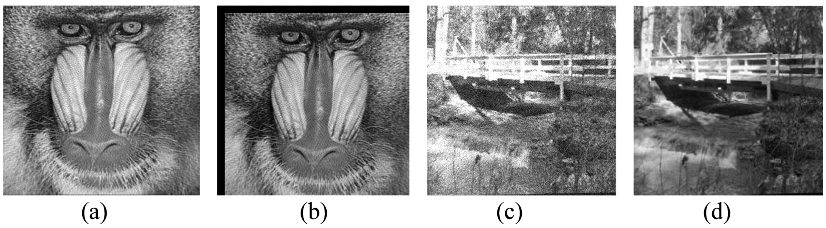


Fig. 6. Watermarked and attacked images by: (a) Compression JPEG_50, (b) Translation_20, (c) Gaussian noise_0.01, (d) Rotation_0.5°

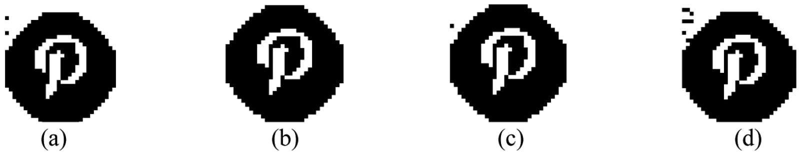


Fig. 7. Recovered watermarks after attacks by: (a) Compression JPEG_50, (b) Translation_20, (c) Gaussian noise_0.01, (d) Rotation_0.5°

The given results show an important correlation between the original and the recovered watermarks. In order to confirm the effectiveness of the proposed watermarking scheme, we represent several comparative studies in the following section.

4.2 Comparative Study

In order to improve the imperceptibility of the proposed method, we compared the PSNR of the original and the watermarked image to the recent approach [3]. Noted that the original image, with size equal to (512 × 512), are watermarked by 256 bits. The following table illustrates the obtained results (Table 2).

Table 2. Imperceptibility comparative study

Host cover images	Baboon		Bridge	
Proposed approaches	[3]	**Ours**	[3]	**Ours**
PSNR (dB)	42.64	**47.83**	43.85	**48.39**

Also, in order to confirm the robustness of the proposed approach and to prove the given advantage by the hybrid decomposition based on DRT and DCT transforms. We are compared the obtained means correlation values of our approach to the proposed approach based on DCT [6] and the proposed one in [8] based on DRT. The given results are illustrated by the following figures (Figs. 8 and 9).

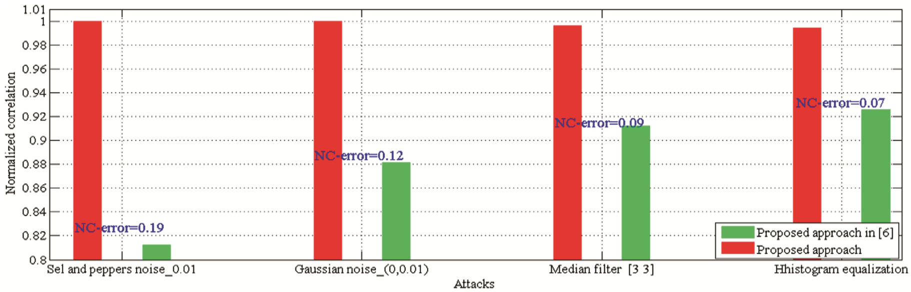


Fig. 8. Comparison of NC between the proposed approach and the proposed approach based on the DCT in [6]

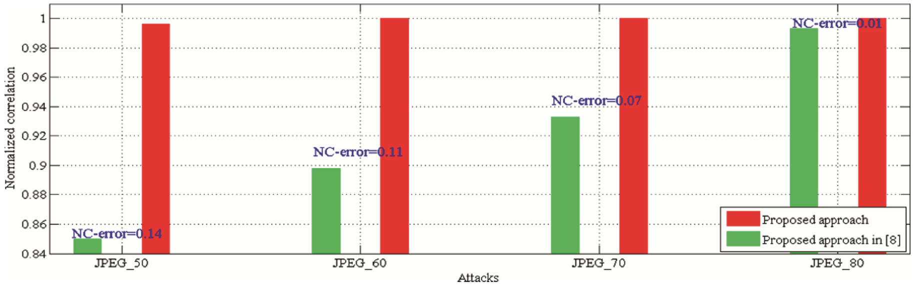


Fig. 9. Comparison of NC robustness to compression attacks of the proposed approach and the proposed approach based on the DRT in [8]

Compared to the proposed approach based on the DRT transform or DCT transform, the proposed approach in the hybrid domain (based on the combination of the DCT and DRT transforms) ensures more robustness to different attacks type. This performance is due to the propriety of the projected-frequency domain.

4.3 Discussion

The results above prove the effectiveness of the proposed watermarking approach to resist to several StirMark attacks. We note that the robustness of the proposed watermarking approach is due to the invariance characteristic of the projected-frequency domain. The watermark is embedded in the higher energy region of the transformed image. So, it contains the important information of the original host cover image. This propriety ensures the robustness of the proposed approach to synchronous and asynchronous attacks. Indeed, the projected-frequency domain represents the hybrid decomposition of an image based on the DRT and DCT methods. Where, the image is projected by using the DRT scheme which ensures the robustness of the proposed approach to geometric distortions. In other side, the frequency representation of the projected image by blocks (8×8) in a similar way of the JPEG compression processing, ensures its robustness to JPEG compression. Also, the important values of the watermarked coefficient ensure the invisibility of the embedded data. In other side, the uses of two coefficients for watermark embedding ensure the blind recovering of the added data. Consequently, the proposed blind watermarking approach in the projected-frequency domain ensures the imperceptibility of the added data and its robustness to synchronous and asynchronous attacks. Also, it allows an important embedding capacity.

5 Conclusion

This paper presents a new blind, robust and imperceptible watermarking scheme with important embedding capacity. This approach performed in a projected-frequency domain which represents a hybrid decomposition based on the DRT and DCT transforms. The combined transformation ensures the considerable performance of the proposed watermarking scheme. Indeed, the projection algorithm ensures the invariance of the transformed image face to geometrical transformations and the frequency decomposition ensures its invariance to compression attacks. In other side, the important values of the transformed image ensure the invisibility of the embedded data. Also, the higher size of the projected-frequency image allows the blind watermarking with embedding capacity more than the watermarking approach based on the transformed image to frequency domain. The imperceptibility and the robustness of the proposed watermarking scheme are proved by simulation results and confirmed by comparative study.

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