Asynchronous Invariant Digital Image Watermarking in Radon Field for Resistant Encrypted Watermark

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Abstract

With the rapid evolution of processing multimedia technologies (text, audio, image and video) and its internet application (wide and easy transmission of digital multimedia contents), the copyright protection has been receiving an increasing attention. Among the existing strategies to protect multimedia online, digital watermarking provides a promising way of protecting data online from illegal manipulation and duplication. In this paper, a new image of watermarking scheme is presented. It performs imperceptible watermarking of color image in the radon domain. The proposed algorithm can resist to geometrical attacks. Experimental results show that the proposed watermarking approach not only can meet the demand on invisibility and robustness of the watermark, but also presents a good performance compared to other proposed methods considered in the comparative study. A mathematical study is developed to demonstrate how and why this approach is robust against geometric transforms.

Keywords: Asynchronous attacks, circular integration transform (CIT), color image watermarking, discrete radon transform, radial integration transform (RIT), robustness

1 Introduction

The rapid development of processing data technologies and internet applications has improved the ease of access to information online. It also increases the problem of illegal copying and redistribution of digital media. Encryption and Stenography are the two techniques introduced to solve data on line. In 1992, the research suggested to use the watermarking technique in data protection.

Nowadays, image watermarking is a protection technology that has attracted a lot of attention. The basic idea of watermarking involves integrating a message into a digital content. This last covers the information to be transmitted in a holder in a way to be invisible and correctly reversible (an algorithm allows the exact extraction of the embedded watermark). Its algorithm requires equilibrium between three constraints: imperceptibility, robustness and embedding capacity [2].

Image watermarking schemes have to keep the image quality and be robust against general image processing and geometric transformation (scaling, rotation and translation) [15]. There are many watermarking algorithms which have been presented in recent literature to protect data against geometric attacks. They can be divided in three main categories. The first one includes watermarking approach which is a watermark detection performing in an invariant domain to geometric attacks. The second category includes methods that detect and correct the geometric attack of the watermarked image in order to perform the detection process. However, another approach for resisting geometric attacks is based on synchronizing, in terms of position, orientation and scaling, use image features to embed and extract the correlating watermark [13].

Various watermarking schemes are proposed for the digital multimedia protection. Most of the schemes perform on the spatial domain where the watermarking techniques directly modify the intensities of selected pixels [4, 5, 6, 8, 9]. Also, several schemes perform on the transformation domain (Fourier-Mellin Transform, Discrete Cosine Transform (DCT), Discrete Fourier Transform (DFT), Discrete Wavelet Transform and the Complex Wavelet Transform (CWT)) where the watermarking algorithm modifies the selected transformed coefficients [10, 16, 18]. In [18], authors used the properties of Fourier transform to develop a watermarking scheme resisting the unavoidable noise and cropping. This algorithm presents a robust watermark strategy for quantum images. The watermark is embedded into the Fourier coefficients of the quantum carrier image. Authors in [15]
proposed a state-coding based on blind watermarking algorithm to embed color image watermark to color host image. This approach used the Integer Wavelet Transform (IWT) and the rules of state coding of the components, R, G and B, of color image watermark and the components, Y, Cr and Cb, of color host image. In the extraction process, authors used also the rules of state coding to recover the original watermark or original host image. In [11], authors proposed an invariant image watermarking scheme by introducing the Polar Harmonic Transform (PHT). This algorithm proposed to resist geometric transformation. Furthermore, Xiao, Ma and Cui have been used for invariance watermarking scheme against global geometric that transforms the Radon field and pseudo-Fourier-Mellin transforms. This combination is named Radon and pseudo-Fourier-Mellin invariants (RPFMI) [17].

In order to resist geometric attacks, we propose a new watermarking algorithm for RGB color image. The proposed approach belongs to the second of the categories that were described above. Imperceptible watermark embedding and detection are performed in the non-conventional radon domain. Our approach selects specific coefficients based on their energy in Radon field to embed watermark. The simulation results proved by mathematical study proved the high efficiency and robustness of the proposed approach. This paper is organized as follows: Section 2 presents an overview of Radon Transformation (RT). Section 3 details our watermarking method. In Section 4, we study the robustness of this technique against different STIRMARK attacks, and we test the ability to detect the embedded watermark in the host image. A study of the watermarked image distortions before and after different attacks is also presented. In Section 5, a mathematical study is developed to explain the resistance of the proposed method and prove the results found. A comparative study with recent published techniques is also presented.

2 Mathematical Recall of Radon Transform

2.1 Generalized Radon Transform

In 1917, Radon, Austrian mathematician, defined the theory of Radon Transform. He proved the possibility to reconstruct a function of a space from knowledge of its integration along the hyper-plans in the same space. This theory establishes the reversibility of the Radon transform and the transition between the native function space and the Radon space, or the space of projections [3]. In image processing, the Radon Transform represents a collection of projections along various directions [14]. The generalized Radon transformation of a 2D continuous function is defined in [1] by the following equation:

\[ R(\rho, \theta) = \int_{-\infty}^{+\infty} \int_{-\infty}^{+\infty} f(x, y) \delta(x \cos \theta + y \sin \theta - \rho) dx dy, \]

where \( \rho \) represents the perpendicular distance of a straight line from the origin, and represents the angle between the distance vector and the x-axis.

The literature proposed two categories of one-dimensional Radon transformation; the first is based on Radial Integration Transform (RIT) and the second is based on the Circular Integration Transform (CIT).

2.1.1 One-Dimensional Radial Integration Transform

The RIT of a function \( f(x, y) \) is defined as the integral of \( f(x, y) \) along a straight line that begins from the origin \((x_0, y_0)\) and has angle \( \theta \) with respect to the horizontal axis (see Figure 1). It is given by the following equation [13]:

\[ R_f(\theta) = \int_0^{+\infty} f(x_0 + u \cos \theta, y_0 + u \sin \theta) du, \]

where \( u \) is the distance from the origin \((x_0, y_0)\) and \( f(x, y) \) is presented by the integral along a straight line that begins from the origin \((x_0, y_0)\) and has an angle with respect to the horizontal axis.

![Figure 1: Representation of the radial integration transform](image)

2.1.2 One-Dimensional Circular Integration Transform

The CIT of a function \( f(x, y) \) is defined as the integral of \( f(x, y) \) along a circle curve with center \( x_0, y_0 \) and radius \( \rho \) (see Figure 2). It is given at [13] by the following equation:

\[ C_f(\rho) = \int_0^{2\pi} f(x_0 + \rho \cos \theta, y_0 + \rho \sin \theta) \rho d\theta, \]

where \( d\theta \) is the corresponding elementary angle and \( f(x, y) \) represents the circle integrated function around the center \((x_0, y_0)\) and by the radius \( \rho \).

2.2 Discrete Radon Transform (DRT)

The discreet Radon transformation 'DRT' of an image \( I(x, y) \) can be defined by the following equations [13]:

\[ R(t\Delta\theta) = \frac{1}{J} \sum_{j=1}^{J} I(x_0 + j\Delta x \cos(t\Delta\theta), y_0 + j\Delta y \sin(t\Delta\theta)). \]
Figure 2: Representation of the circular integration transform

\[ C(k\Delta\rho) = \frac{1}{T} \sum_{t=1}^{T} I(x_0 + k\Delta\rho \cos(t\Delta\theta), y_0 + k\Delta\rho \sin(t\Delta\theta)), \]

where \(d\theta\) represents the angular variation step, \(\Delta s\) is the scaling step, \(k\Delta\rho\) represents the radius of the smallest circle that encircles the image, \(J\) represents the number of samples on the radius with orientation \(\theta\), \(t = 1, ..., 360\Delta\theta\) and \(k = 1, ..., \frac{360}{\Delta\theta}\).

The Radon transformation of the image \(I(x,y)\) of size \([M,N]\) generate a matrix \(R(\rho,\theta)\) of a size equal to \([N\rho,N\theta]\) with real coefficient representing the radon field with:

\[
\begin{cases}
N\rho &= \sqrt{N^2 + M^2} + 1 \\
M\rho &= \frac{M_{\text{max}}}{\Delta\theta}
\end{cases}
\]

(1)

3 The Proposed Watermarking Approach

The literature suggested that the Radon Transform properties are much recommended in watermarking applications in which resistance to geometric attacks. A watermark embedding and detection scheme using these properties are described in the proposed watermarking approach. Also, due to the expansion of the projected image matrix from its size \([M,N]\) to \([M\rho,N\theta]\) this field allows a higher amount of embedded data. In fact the DRT increases the size of the transformed image (see Equation (1)). The proposed method consists in embedding the watermark in selected coefficients in the radon field. These coefficients are chosen from the area of maximal energy. They represent maxims in the Radon coefficients and must respect the following three essential characteristics:

- These coefficients are set on the integral line of projection, so they will be well recovered from the inverse radon transform.
- Secondly, they contain the most important details of the original images. Consequently, they are the most adapted to a code in a watermark with better imperceptibility.
- Their high values enable us to hide the binary coefficients of the watermark without any perceptual degradation.

3.1 Details of the Proposed Algorithm

In the following Sections, we will note the original watermark as \(W_o\), the encrypted embedded watermark as \(W\), the recovered encrypted watermark as \(W\), the recovered decrypted watermark as \(W_o\), the Original RGB color image (support or host image) as \(I\), the original blue matrix of the host image as \(I_b\), the transformed channel blue (matrix blue) of the host image in Radon field as \(R_b\), the watermarked channel blue (matrix blue) of the host image in Radon field as \(R_{bw}\), the watermarked blue matrix in spatial field as \(I_{bw}\), \(I_w\) represents the watermarked spatial image and the transformed channel blue (matrix blue) of the watermarked host image in Radon field as \(R'_{bw}\). Likewise, \((x, y)\) represents the spatial coordinates of the original image, \((\rho, \theta)\) represents the coordinates of the color image in the radon field and \(k\) and \(l\) are the coded bits representing the watermark, \([M_w,N_w]\) represents the size of the original image, \([M,N]\) represents the size of original watermark, \([N\rho,N\theta]\) represents the size of the image in radon domain and \(G\) is the embedding strength.

3.1.1 Watermark Embedding Process

The main concept of the watermark embedding process is shown in Figure 3.

![Watermarking algorithm](image)

Figure 3: Watermarking algorithm

For the RGB color image, the red, green and blue channels are candidates for watermark embedding as human eyes are not sensitive on the modification of blue channel than the green and red channels. Besides, Watermarking in the blue channel allows good invisibility and higher
embedding capacity. Therefore, we propose to embed the watermark in the blue channel of the selected color image [7]. The proposed algorithm is described in the following steps:

**Step 1: Encrypt the watermark.**

In order to encrypt the watermark, we use the following steps:

1) Transform the original watermark $W_o$ into a one dimensional vector $V_{water}$ by the following equation:

$$W_o(x, y) \rightarrow V_{water}(l).$$

2) Decompose the watermark in $N$ equal blocks $B_i$, where

$$V_{water}(N) = \{B_1, B_2, ..., B_N\}.$$  

3) Generate a key $key$ with its length is equal to the length of the block $B_i$.

4) Encrypt the first block $B_1$ by using the following equation:

$$Bc_1 = B_1 \oplus key.$$  

5) Encrypt the second block $B_2$ by using the following equation:

$$Bc_2 = B_2 \oplus Bc_1.$$  

6) Generally, after each encrypting iterates of each block $B_i$, the resulting encrypted blocks $Bc_i$ is used to encrypt the next block $Bc_{i+1}$, where $i = 3, 4, 5, ..., N$.

$$Bc_i = B_i \oplus Bc_{i-1}.$$  

7) After encrypting the watermark by using the function "XOR", we applied $S_{max}$ iteratively permutations on the encrypted watermark vector in order to improve the encryption system. The first permuted iteration is defined by the following equation:

$$P_{s=1}(B_1, ..., B_N) = W_o : B_{N/2}, ..., B_1, B_N, ..., B_{(N/2)+1}.$$  

We continue the permutation process by applying the defined function as follows:

$$P_{s=\alpha}(Bc_1, ..., Bc_N) = P_{s=\alpha-1}Bc_N, ..., Bc_{(N/2)}, Bc_1, ..., Bc_{(N/2)+1},$$  

where $\alpha = 2 \rightarrow S_{max}$ and $S_{max}$ represents the number of the permutation iteration. The encrypted watermark vector $V_c$ is obtained after $S_{max}$ permutations and it is defined as follows:

$$V_c(l) = P_{s=20}(l).$$

To obtain the encrypted watermark, we transformed the vector $V_c$ to matrix with size equal to $[M_w, N_w]$ defined as follows:

$$V_c(l) \rightarrow W(x, y).$$

**Step 2: Select the radon coefficients to embed the watermark.**

In this step, a discrete radon transform is applied only on the blue channel $I_b$ of the color image $I$. A selection of a set of coefficients having the higher energy from this transformed matrix called $R_b$ is done. The number of the selected coefficient is equal to $M_w \times N_w$ which represents the length of the encrypted watermark. For this reason, we transform the image matrix into a vector $V$ by using the following equation:

$$Rb(\rho, \theta) \rightarrow V(k).$$

Then, the vector $V$ is organized in downward order. It is defined as follows:

$$V(1) > V(2) > V(3) > ... > V(k-1) > V(k),$$

where $K = M_b \times N_b$. Next, we select the used coefficients to embed the watermark. They represent the $M_w \times N_w$ first highest coefficients in the matrix $R_b$. For this process, we use the following steps:

1) Define the threshold $\lambda_{opt}$ : It represents the coefficient number $M_w \times N_w$ in the vector $V$:

$$\lambda_{opt} = V(M_w \times N_w).$$

2) Select the coefficients to be used for watermark coding:

$$R_E(\rho, \theta) = R_b(\rho, \theta) \quad \text{where} \quad R_b(\rho, \theta) \geq \lambda_{opt}.$$  

So, the selected coefficient to encode the watermark represent the $M_w \times N_w$ first coefficients in the vector $V$:

$$R_E(\rho, \theta) = V(l).$$

**Step 3: Embedding process.**

The embedding process is described in Figure 4. Each selected coefficient coded one bits of the encrypted watermark vector $V_c$. To embed watermark in the selected coefficient of the matrix $R_b$, we used the following equation:

$$\begin{cases} R_{bw}(\rho, \theta) = R_b(\rho, \theta) + G & \text{if } V_c(l) = 1 \\ R_{bw}(\rho, \theta) = R_b(\rho, \theta) - G & \text{if } V_c(l) = 0 \end{cases}$$

Also, we use the vectors $Er, E\rho$ and $E\theta$ to save the amplitude, the position $\rho$ and the position $\theta$ of each selected coefficient $R_b(\rho, \theta)$. These vectors have the length $M_w \times N_w$. They are used later to recover the embedding watermark. These vectors are filled by using the following equations:

$$Er(c) = R_b(\rho, \theta).$$
Step 4: Watermarking image in spatial field.
We transform the watermarking blue matrix $R_{bw}$ by
the inverse DRT (IDRT) and we combine the RGB
channels of the image to create the watermarked
color image in spatial domain $I_w$.

3.1.2 Watermark Recovering Process
This algorithm represents the second principal algorithm
in every watermarking approach. It serves to recover the
embedded information with minimal loss. For this rea-
son, it is necessary to respect the used parameter of the
processing field and to use the details of the embedding
program in this approach. This process is detailed by the
illustrated in Figure 5.

In this algorithm, we extract the blue channel $I_{bw}$. Then, we apply a radon transform with the same pa-
rameter used in the embedding process (step2 and step 3
in paragraph 3.1.1) for the extracted channel. This trans-
formation gives the watermarked blue channel in radon
field $R'_{bw}$. Next, we use the two saved vectors $E_\rho$ and
$E_\theta$ detect the position of the used coefficient to embed
the encrypted watermark. The amplitudes of the detect-
ing coefficients are saved in the vector $E_r'$ by using the
following equation:

$$E_r'(cl) = R'_{bw}(E_\rho(cl), E_\theta(cl)),$$

where $cl = 1, 2, 3, ..., M_w \times N_w$. This vector contains the
used coefficients in embedding the watermark. In order
to decide if the embedding bits is equal to 1 or 0. We
compare the two saved vectors $E_r'$ and $E_r$ bit by bits and
its difference with the selected threshold $T$. In this step,
we use the comparison test defined as follows:

$$W'(l) = 1 \text{ if } E_r(l) \geq E_r'(l) \text{ and } E_r'(l) - E_r(l) > T$$
$$W'(l) = 0 \text{ else.}$$

The recovered watermark $W'$ is a one-dimensional vec-
tor which represents the encrypted watermark. To de-
crypt it, we use the same algorithm used to encrypt the
original watermark with the same parameters and steps.
It is defined as follows:

1) Decompose the recovered encrypted watermark vec-
itor in $N$ equal blocks $B'_i$ with length equal to the
length of the blocks $B_i$ where $i = 1, 2, ..., N$: $V_{water}(N) = B'_1, B'_2, ..., B'_N$.

2) In order to recover the original watermark, we apply
$S_{max}$ iteratively inverses permutations to the recover
encrypted watermark vector. The first inverse permuta-
tion is defined as follows:

$$P_{s^{-1}}(B'_1, B'_2, ..., B'_N) = V_{water}(B'_{(N/2)+1}, ..., B'_N, B'_1, B'_2, ..., B'_{(N/2)})$$

The next of the inverse permutation process defined by
the following equation:

$$P_{s^{-1}}(B'_1, B'_2, ..., B'_N) = P_{s^{-1}}(B'_{(N/2)+1}, ..., B'_N, B'_1, B'_2, ..., B'_{(N/2)})$$

Figure 4: Embedding process

$$E_\theta(y) = \theta$$
$$E_\rho(x) = \rho.$$
where \( \alpha = 2 \rightarrow S_{\text{max}} \) and \( S_{\text{max}} \) represents the number of the permutation iteration used in the embedding watermark process. The decrypted watermark vector after \( S_{\text{max}} \) inverse permutation \( V_d \) it is defined as follows:

\[
V_d(l) = P_{S=S_{\text{max}}}^{-1}(l).
\]

3) Devise \( V_d \) into blocks \( B'_i \) with equal length equal to the length of the blocks \( B_i \) where \( i = 1, 2, ..., N \). Use the same key sing in the embedding process \( \text{key}0 \) to decrypt the first block \( B_{r1} \) by using the following equation:

\[
B_{r1} = B'_1 \oplus \text{key}0.
\]

4) Decrypt the second block \( B'_2 \) by using the following equation:

\[
B_{r2} = B'_2 \oplus B'_1.
\]

5) Generally, after each decrypting iterates of each block \( B_{ri} \), the resulting decrypted blocks is used to decrypt the next block \( B_{ri+1} \) where \( i = 3, 4, ..., N - 1, N \).

\[
B_{ri} = B'_i \oplus B'_{i-1}.
\]

6) The decrypted watermark after application of XOR function is defined as follows:

\[
V'_d(N) = B_{r1}, B_{r2}, ..., B_{rN}.
\]

Finally, to obtain the decrypted watermark, we transformed the vector \( V_d \) to matrix with size equal to \( [M_w \times N_w] \) defined as follows:

\[
V'_d(N) \rightarrow W'_o(x, y).
\]

\( W'_o \) is the recover watermark.

### 3.2 Experimental Results

To evaluate the performance of the proposed watermarking scheme, we use a data base composed with 100 logical watermarks coded on 0 and 1 binary \( (d = 2) \) and 50 host cover images. Different tests give results close to the present results in this paper. In this work, we present the results of the standard Lena image RGB color (see Fig.18) with size \( (256 \times 256) \) and a watermark with a size \( (80 \times 80) \) (see Figure 20). We apply a discrete radon transform to the original image with an integration angle path "in degree \( \Delta \theta = 1 \) for \( \theta \in [0,2\pi] \) and an integration scale path \( \Delta \rho = 1 \) pixels for \( \rho \in [0,\sqrt{M^2 + N^2} + 1] \).

The similitude rate between the extracted watermark and the original watermark is continuously computed to test the robustness of this approach. This is done by the normalized Cross-correlation presented in the following equation:

\[
NC = \frac{\sum_{i=1}^{M_x} \sum_{j=1}^{N_x} \sum_{i=1}^{M_y} \sum_{j=1}^{N_y} W_o W'_o}{\sqrt{\sum_{i=1}^{M_x} \sum_{j=1}^{N_x} \sum_{i=1}^{M_y} \sum_{j=1}^{N_y} W_o^2 \sum_{i=1}^{M_y} \sum_{j=1}^{N_y} W'_o^2}}.
\]

On the other hand, the imperceptibility of the embedded watermark is a constraint that must be respected. A measure of similarity rate based on the PSNR described by the following equation is computed after each watermarking process with respect to the gain factor used. A threshold of \( 37 \) \( dB \) is fixed to verify if some distortions begin to appear on the watermarked image in addition to a psycho-visual decision.

\[
\text{PSNR} = 10 \log \left( \frac{d^2}{MSE} \right).
\]

Where \( d \) represents the maximal image intensities \( (d = 256 \) for the host cover image and \( d = 2 \) for the used logical watermark in our case) and \( MSE \) is calculated in the following equation:

\[
MSE = \frac{1}{M_w \times N_w} \sum_{i=1}^{M_w \times N_w} (W_o - W'_o)^2.
\]

The first step of this simulation study consists to select the threshold \( \lambda \) uses to select the encoding coefficients used to embed the watermark.

#### 3.2.1 Selection of the Threshold \( \lambda \)

The threshold \( \lambda \) which is chosen for selecting the zero coefficients will be used to embed the watermark in order to improve the robustness of the proposed watermarking scheme against different attacks categories. For that purpose, it is provided in the following five different values of \( \lambda \), \( \lambda_0, \lambda_{\text{min}}, \lambda_{\text{meas.-inf}}, \lambda_{\text{meas.-max}} \) and \( \lambda_{\text{max}} \), used to select the encoding coefficients. A comparative study is performed to select the optimum threshold used to select the embedding coefficients.

1) Watermarking in coefficients equal to 0.

To select the encoded coefficients \( R_E(\rho, \theta) \), we used a threshold \( \lambda_0 = 0 \). The number of the selected coefficient is equal to \( M_w \times N_w \) where:

\[
\begin{align*}
\text{if } R_0(\rho, \theta) &= \lambda_0 & \text{then } R_E(\rho, \theta) &= R_0(\rho, \theta). \\
\text{if } R_0(\rho, \theta) &= 0 & \text{then } \text{count} &= \text{count} + 1; \\
\end{align*}
\]

The simulations tests show that we cannot recover the embedding watermark in the coefficients equal to 0. So, the comparative parameters give the following results: \( C = N\alpha N, \text{PSNR} = N\alpha N \) and \( \text{BER} = 6400\text{bits} = 100\% \).

2) Watermarking in minimal coefficients different to 0.

In this algorithm, the coefficients whose values are minimal and different from zero are selected. For this reason we used a counter "count" to compute the number of zero in the matrix \( R_0(\rho, \theta) \):

\[
\begin{align*}
\text{count} &= 0; \\
\text{if } R_0(\rho, \theta) &= 0 & \text{then } \text{count} &= \text{count} + 1; \\
\end{align*}
\]

The threshold \( \lambda_{\text{min}} \) is selected as follows:

\[
\lambda_{\text{min}} = V(((\text{len} - \text{count}) - (M_w \times N_w)) + 1),
\]

end.
where $len$ is the length $V$ of the vector representing the coefficients of the host radon image organized in downward order.

The selected coefficient to embed watermark are:

$$R_E(\rho, \theta) = R_b(\rho, \theta) \text{ where } R_b(\rho, \theta) \leq \lambda_{\min} \text{ and } R_b(\rho, \theta) \neq 0.$$  

The simulations tests give a threshold $\lambda_{\min} = 5073$ and they show that we can recover the embedding watermark by the following parameter quality results: $C = 0.3023$, $PSNR = 52.3670dB$, $BER = 2413bits = 37.70\%$. The visual results given in Figures 6 and 7.

3) Watermarking in maximal coefficients.

The used process to define $\lambda_{\max}$ is same of the defined process in step 2 of the paragraph 3.1.1 (watermark embedding process) where $\lambda_{\max} = \lambda_{\opt}$.

The simulations tests give a threshold $\lambda_{\max} = 32208$ and they show that we can recover the embedding watermark by the following parameters quality results: $C = 1$, $PSNR = Inf$ and $BER = 0bits = 0\%$. The visual results given in Figures 8 and 9.

4) Watermarking in the higher coefficients to $\lambda_{\text{means}}$ and different to the maximal coefficients.

In this algorithm the selected coefficient to embed watermark are:

$$R_E(\rho, \theta) = R_b(\rho, \theta) \text{ where } R_b(\rho, \theta) > \lambda_{\text{means}} \text{ and } R_b(\rho, \theta) < \lambda_{\max}.$$  

The used threshold in this algorithm is noted by $\lambda_{\text{means-sup}}$. The simulations results give $\lambda_{\text{means-sup}} = 18842$ and $\lambda_{\max} = 32208$. The simulation tests show that we can recover the embedding watermark by the following parameter quality results: $C = 0.9149$, $PSNR = 62.5942$ and $BER = 229bits = 3.57\%$. The visual results given in Figures 10 and 11.

5) Watermarking in the less coefficients to $\lambda_{\text{means}}$ and different to the minimal coefficients.

In this algorithm the selected coefficient to embed watermark are:

$$R_E(\rho, \theta) = R_b(\rho, \theta) \text{ where } R_b(\rho, \theta) < \lambda_{\text{means}} \text{ and } R_b(\rho, \theta) > \lambda_{\min}.$$  

The used threshold in this algorithm is noted by $\lambda_{\text{means-inf}}$. The simulations results give $\lambda_{\text{means-inf}} = 18842$ and $\lambda_{\min} = 5073$. The simulation tests show that we can recover the embedding watermark by the following parameter quality results: $C = 0.7957$, $PSNR = 58.8606$ and $BER = 541bits = 8.45\%$. The visual results given Figures 12 and 13.

6) Comparative study to select $\lambda$.

Figures 14, 15, and 16 show the variation of the correlation, PSNR and BER of the recovered watermark for different values of threshold $\lambda$. 

Figure 6: Watermarking image in radon field  
Figure 7: Recovered watermark

Figure 8: Watermarking image in radon field  
Figure 9: Recovered watermark

Figure 10: Watermarking image in radon field  
Figure 11: Recovered watermark

Figure 12: Watermarking image in radon field  
Figure 13: Recovered watermark

Figure 14: Watermarking image in radon field  
Figure 15: Recovered watermark

Figure 16: Watermarking image in radon field  
Figure 17: Recovered watermark
3.2.2 Robustness of the Proposed Watermarking Approach

An example of an original and a watermarked image is illustrated in Figure 17 and 18. The set of Figures 19, 20 and 21 illustrate respectively the original watermark, the encrypted one and the decrypted recovered watermark from the radon field.

Figures 14, 15, and 16 show that the more threshold $\lambda$ increases the better the correlation of the recovered watermark becomes. So, the optimum threshold $\lambda$ is $\lambda_{opt} = \lambda_{max}$. Generally, the robustness of the proposed method against synchronous and asynchronous attacks for the higher coefficient depends on the highest energy of the radon region. The important peaks of radon domain are located at the points corresponding to the projection parameter. Besides, the coefficients of the radon region in which the highest energy is located and set on the line of projection contain the significant information of the original image. So, they allow a good recovery of the transformed information with inverse radon transform.

In the simulation test, we use a factor gain $G = 1000$ to embed the watermark in the selected coefficient in radon field. These coefficients are higher to $\lambda_{opt} = 32208$. This application gives a PSNR value between the original and the watermarked host image equal to $PSNR = 30.89 \text{dB}$. The normalized cross-correlation between original and correlating watermark is $NC = 1$. So, no visible differences are detected between the original and the recovered watermark.

In order to improve the correction of the recovered watermark, we insist in this version that the embedded watermark is binary coded on 0 and 1. So, it allows just two different intensities scale. Consequently, the used factor d to compute the PSNR between original and recovered watermark is equal to 2 and gives the present results in Tables 1 and 2.

Tables 1 and 2 show the effectiveness of the proposed watermarking approach to resist the different STIR-MARK attacks. We note that the resistivity of the proposed approach against geometric attacks is very high. This efficiency is related to the properties of the Discreet Radon Transform. Also, the effectiveness of the proposed method to resist common image processing attacks is related to an accurate selection of the coefficients which are selected from the image in Radon field. These coefficients presenting the highest energy in the Radon field contain...
Table 1: Resistance of the proposed method against the common image processing attacks

<table>
<thead>
<tr>
<th>ATTACKS</th>
<th>NC</th>
<th>PSNR</th>
<th>BER</th>
<th>bits</th>
<th>percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conv2</td>
<td>1</td>
<td>inf</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Median3</td>
<td>0.9878</td>
<td>71.0075</td>
<td>33</td>
<td>0.51</td>
<td></td>
</tr>
<tr>
<td>Median5</td>
<td>0.9793</td>
<td>68.7107</td>
<td>56</td>
<td>0.875</td>
<td></td>
</tr>
<tr>
<td>Median7</td>
<td>0.9841</td>
<td>69.8579</td>
<td>43</td>
<td>0.67</td>
<td></td>
</tr>
<tr>
<td>PSNR0</td>
<td>0.9149</td>
<td>62.5942</td>
<td>229</td>
<td>3.578</td>
<td></td>
</tr>
<tr>
<td>PSNR3</td>
<td>1</td>
<td>inf</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Noise20</td>
<td>0.9863</td>
<td>70.5106</td>
<td>37</td>
<td>0.578</td>
<td></td>
</tr>
<tr>
<td>Noise40</td>
<td>0.9826</td>
<td>69.4716</td>
<td>47</td>
<td>0.73</td>
<td></td>
</tr>
<tr>
<td>JPEG50</td>
<td>0.9413</td>
<td>63.9654</td>
<td>167</td>
<td>2.6</td>
<td></td>
</tr>
<tr>
<td>JPEG70</td>
<td>0.9974</td>
<td>77.7416</td>
<td>7</td>
<td>0.109</td>
<td></td>
</tr>
<tr>
<td>JPEG80</td>
<td>1</td>
<td>inf</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

The significant information of the original image, which allow the withstanding against the common image processing attacks. These coefficients are located and set on the line of projection, so they allow a good recuperation of transformed information with inverse radon transform. This robustness is mathematically proved in the following Section. The following images illustrate zoomed views of the selected coefficients in the Radon field “Figure 22” and the coded watermark in these coefficients illustrated in the figure “Figure 23”.

Figure 22: The used sets of coefficient to embed watermark in Radon field

Figure 23: The sets of watermarked coefficient the watermark presence in the Radon field

In another hand, the watermarked image is illustrated in Figure 18. It represents an imperceptible watermarking scheme. We will prove in the following mathematical study why the watermarking system in radon field represents an imperceptible watermarking approach. In fact, embedding information in radon coefficient especially in the higher radon coefficients under the perceptibility threshold is defined by the Weber law. We note the data loss "error" between the recovered images after inverse radon transform of the original image $I'(x, y)$ and the watermarked image $I(x, y)$ by $\varepsilon$. The following equations prove that error has no visual effect on the watermarked image.

$$I'(x, y) - I_w(x, y) = \varepsilon(x, y)$$

or the Weber law imposes that:

$$\sum_{i=1}^{M} \sum_{j=1}^{N} \frac{I'(i, j) - I(i, j)}{I'(i, j)} \leq \tau$$

where $\tau \approx (2\% - 3\%)$.

Since the simulation results proved that $\varepsilon < \tau$. So, perceptually we can say that no visible changes are engendered by the watermarking approach in radon domain, then:

$$I' = I$$ and $\varepsilon \to 0$.

Figures 24, 25, and 26 illustrate an original and Radon transformed image followed by the positions (In red) of the imperceptible distortions introduced by applying the radon transform and recovering the image by the inverse Radon transform without any watermark embedding.
4 Justifying Robustness Against Asynchronous Attacks

In these Sections, we improve that the watermarking image in radon field presenting a more robustness against asynchronous attacks presented in table I is proved. In addition, when dealing with image, this transform doesn’t engender any perceptual degradation.

4.1 Linearity

given \( g(x, y) = \beta I(x, y) \) where \( \beta \) is a constant. The DRT of \( g(x, y) \) gives the following relation:

\[
DRT[g(x, y)] = R_1(\rho, \theta) \quad \text{where} \quad \frac{R_1(\rho, \theta)}{R(\rho, \theta)} = \beta',
\]

or \( \beta' = \beta + \Delta \beta \) through different tests we find that:

\[
\Delta \beta \ll \ll \ll \beta \quad \text{so} \quad \beta' \approx \beta.
\]

**Do:** \( R_1(\rho, \theta) = \beta R(\rho, \theta) \).

**So:** \( DRT[g(x, y)] = \beta DRT[I(x, y)] \).

Similarly, we define the following relationship:

\[
I_f : g(x, y) = \beta_1 I_1(x, y) + \beta_2 J(x, y).
\]

The Radon Transformation of \( J \) gives the following results:

\[
DRT[g(x, y)] = \beta_1 DRT[I_1(x, y)] + \beta_2 DRT[J(x, y)],
\]

where \([I_1(x, y)]\) and \([J(x, y)]\) are two image defined in spatial field and \( \beta_1 \) and \( \beta_2 \) are two constants. This relation proves that the DRT is linearly invariant.

4.2 Image Scaling

A scaling on the \( \overrightarrow{X} \) and \( \overrightarrow{Y} \) axis of the image is applied as presented in Figure 27 and the following equation:

\[
g(x, y) = I(x - x_0, y - y_0).
\]

The Radon transform of \( J(x, y) \) is as follows:

\[
DRT[g(x, y)] = R_1(\rho_1, \theta) = DRT[I(x - x_0, y - y_0)].
\]
where

\[
\begin{align*}
\rho_1 &= (x - x_0) \cos \theta + (y - y_0) \sin \theta \\
&= x \cos \theta - x_0 \cos \theta + y \sin \theta - y_0 \sin \theta \\
&= x \cos \theta + y \sin \theta - x_0 \cos \theta - y_0 \sin \theta \\
&= \rho - x_0 \cos \theta - y_0 \sin \theta.
\end{align*}
\]

So:

\[
DRT[g(x, y)] = R_1(\rho_1, \theta) = R(\rho - x_0 \cos \theta - y_0 \sin \theta, \theta).
\]

Also, the error defined by \(\Delta \rho = -x_0 \cos \theta - y_0 \sin \theta, \theta\) is lower than the value of \(\rho\). Since the variation \(\Delta \rho\) cannot allow the projection of a pixel neighbor defined by its coordinates \((\rho, \theta)\) due to its size \(\Delta \rho \ll \rho\) then, the radon transformation depends only on the value of \(\rho\).

### 4.3 Image Rotation

Supposing that \(K(\rho, \theta)\) represents the polar coordinate of \(I(x, y)\) and \(g(\rho, \theta) = K(\rho, \theta - \varphi)\) with \(\varphi\) represents the angle of circular shifting. The results of rotating a spatial image in the radon field is studied and presented in Figure 28 and the following equations:

\[
\begin{align*}
DRT[g(\rho, \theta)] &= DRT[K(\rho, \theta - \varphi)] = R_1(\rho_1, \theta_1) \\
&= I(x \cos \theta \cos \varphi + y \sin \theta \sin \varphi, \neg y \cos \theta \sin \varphi + y \sin \theta \cos \varphi) \\
R_1(\rho_1, \theta_1) &= I(x \cos(\theta - \varphi), y \sin(\theta - \varphi)). \\
\rho_1 &= \rho \\
\theta_1 &= \theta - \varphi.
\end{align*}
\]

So,

\[
DRT[g(\rho, \theta)] = R_1(\rho_1, \theta_1) = R(\rho, \theta - \varphi).
\]

This relation shows that the radon transform depends only on the value of \(\theta - \varphi\) and its magnitude is constant. Consequently the projected pixel will change its location in the Radon field according to the angular rotation applied. This proves that angular rotations are conserved to generate the correspondent Radon coefficients.

### 4.4 Cropping Rotation and Scaling

In this section, we test the invariance of the DRT if different asynchronous attacks are combined simultaneously such as rotation and scaling or cropping without changing the axis projection.

**Case 1.** Scaling on Y axis and circular shifting by an angle (See Figure 29).

\[
\begin{align*}
DRT[g(\rho, \theta)] &= DRT[K(\rho, \theta - \varphi)] = R_1(\rho_1, \theta_1) \\
&= I(x \cos \theta \cos \varphi + x \sin \theta \sin \varphi, \neg y \cos \theta \sin \varphi + (y - y_0) \sin \theta \cos \varphi) \\
R_1(\rho_1, \theta_1) &= I(x \cos(\theta - \varphi), (y - y_0) \sin(\theta - \varphi)). \\
\rho_1 &= \rho - y_0 \sin(\theta - \varphi) \\
\theta_1 &= \theta - \varphi.
\end{align*}
\]

So, in this case:

\[
DRT[K(\rho, \theta - \varphi)] = R(\rho - y_0 \sin(\theta - \varphi), \theta - \varphi).
\]

The error is defined by:

\[
\Delta \rho = -y_0 \sin(\theta - \varphi) \ll \rho.
\]

Experimental proof tested that the error found is very small compared with \(\rho\) (\(\Delta \rho \ll \rho\)).

**Figure 29:** Scaling on Y axis and circular shifting by an angle

**Case 2.** Scaling on Xaxis and circular shifted of crop in image (See Figure 30).

\[
\begin{align*}
DRT[g(\rho, \theta)] &= DRT[K(\rho, \theta - \varphi)] = R_1(\rho_1, \theta_1) \\
&= I((x - x_0) \cos \theta \cos \varphi + (x - x_0) \sin \theta \sin \varphi, \neg y \cos \theta \sin \varphi + y \sin \theta \cos \varphi) \\
R_1(\rho_1, \theta_1) &= I((x - x_0) \cos(\theta - \varphi), y \sin(\theta - \varphi)). \\
\rho_1 &= \rho - x_0 \cos(\theta - \varphi) \\
\theta_1 &= \theta - \varphi.
\end{align*}
\]

So,

\[
DRT[K(\rho, \theta - \varphi)] = R(\rho - x_0 \cos(\theta - \varphi), \theta - \varphi).
\]

The error is

\[
\Delta \rho = -x_0 \cos(\theta - \varphi) \ll \rho.
\]

**Figure 30:** Scaling on Xaxis and circular shifted of crop in image
Case 3. Scaling on Xaxis and circular shifted of crop in image (See Figure 31).

\[
DRT[g(\rho, \theta)] = DRT[K(\rho, \theta - \varphi)] = R_1(\rho_1, \theta_1)
\]

\[
R_1(\rho_1, \theta_1) = I((x - x_0) \cos \theta \cos \varphi + (x - x_0) \sin \theta \sin \varphi,
-(Y - Y_0) \cos \theta \sin \varphi + (Y - Y_0) \sin \theta \cos \varphi).
\]

\[
\rho_1 = \rho - x_0 \cos(\theta - \varphi) - y_0 \sin(\theta - \varphi),
\theta_1 = \theta - \varphi.
\]

So, in this case:

\[
DRT[K(\rho, \theta - \varphi)] = R(\rho - x_0 \cos(\theta - \varphi) - y_0 \sin(\theta - \varphi), \theta - \varphi).
\]

The error is defined by:

\[
\Delta \rho = x_0 \cos(\theta - \varphi) y_0 \sin(\theta - \varphi).
\]

Figure 31: Scaling on X and T axis and circular shifted of crop in image

Due to its feeble value, the error \( \Delta \rho \) cannot change the original integer quantized coefficient in Radon field. So, the used coefficient to code the watermark does not change and the watermark is correctly recovered. As proved above, face to singular or composed geometric transform, the Radon transform offers invariance to the transformed image. Consequently, the distortions and geometric transforms applied on the spatial watermarked image have generally no effect on the embedded watermark in the radon field since these variations are conserved over the Radon coefficients where the watermark is coded.

5 Comparative Study

In order to prove the efficiency and high robustness of the proposed method, a comparison study illustrated in Figures 32 and 33 is conducted with recent proposed approach in the literature exploiting the Radon domain [12] and [17].

Compared to the proposed methods in [12] and [17], Figure 32 and Figure 33 show that the robustness of the proposed watermarking scheme in the radon field is more effective than the previous schemes. This efficiency is due to the propriety of radon field and its performance in detecting the important peaks by using the inverse radon transform. The proposed watermarking scheme does not degrade the visual perception of the watermarked image and it is robust against the two categories of attacks.

6 Conclusions

In this paper a watermarking approach based on the Radon transform is presented. The watermark is coded in selected coefficients with respect to specific mathematical characteristics and the energy is characterized by
higher robustness against various attacks types. The proposed scheme presents high robustness especially against asynchronous attacks. This resistance against these geometric attacks is studied and proved mathematically. Accordingly, the equilibrium between watermarking constraints is achieved. Robustness and imperceptibility are respected and the embedding capacity is increased.

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References


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