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Research paper

Robust image watermarking based on QR factorization and LWT

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Abstract

Personal information needs to be safely transmitted over the internet and addressed effectively. Robust watermarking of biometric patterns is a convenient technique used to increase security and data authentication, which is decisive due to the uniqueness of some types of watermark images. Biometrics like fingerprints, voice, retina, iris, and blood vessel tree are being increasingly utilized for affirmative identification since they cannot be mislaid or forgotten and represent perceptible components. Furthermore, from the viewpoint of linear algebra, any digital image can be expressed by a matrix consists of a non-negative number of scalars. The objective of this paper is to intro-duce a newfangled blind watermarking algorithm using matrix decomposition method named QR. The application and analysis of the QR Matrix decomposition technique illustrate its impact on each block of the LH2 subband in the frequency domain that represents the output of two-level LWT (Lifting Wavelet Transform). The experimental results display that the newly proposed mechanism is secure and imperceptible. The final conclusion shows that the proposed method can get better PSNRs and that the proposed algorithm fulfills better watermark imperceptibility and robustness beneath different attacks.

Keywords: *Imperceptibility; Lifting Wavelet Transform (LWT); QR Matrix Factorization; Robustness; Watermarking.*

1. Introduction

Linear algebra is a subfield of mathematics interested with matrices, vectors, and linear transforms. It is a fundamental key to the field of image processing, from symbols used to describe the approach of algorithms to the enforcement of algorithms in code. On the other hand, linear algebra plays an important role in image processing, particularly in watermarking.

Digital image watermarking is information (the watermark) hiding into the digital data. In other words, to affirm the originality of the data; the embedded secret image can be specified or extracted later. Digital watermarking is the first kind of mechanisms to better the impartiality and reliability of digital data. Lately, authentication is one of the major watermarking requirements in image processing applications [1].

A worthy tool in numerical linear algebra named Schur decomposition is used by Thajeel et al. [2] to fulfill security, robustness, and imperceptibility of watermarking exigencies. In [3] a factorization method LU decompose a matrix into a product of two matrices, an upper triangular matrix and a lower triangular matrix such that the main diagonal equal to 1. In the lower triangular matrix L there is a specific correspondence between any two factors in the first column after implementing LU decomposition on 4×4 sub image. LU factorization has perfect energy divisions, so it supplies a franker reference for selecting the position of the watermark embedding [4].

Furthermore, SVD (singular value decomposition) and upper-and-lower (LU) factorization have a modicum effect on the perception of the watermark. So, Jane, Elbaşi [5] gave incorporation of DWT and SVD through LU factorization as a new non-blind watermarking method that demands cover work to reveal the watermark.

An analysis of the SVD-based watermarking scheme and its impact on the spatial domain are investigated in [6]. The mathematical features of SVD and the analysis given in [6], enabled Zhang et al. to provide a robust image watermarking algorithm in which a binary watermark is embedded into the largest singular value of each block in the spatial domain.

Motivated by the above, this paper focus on a digital watermarking algorithm depends primarily on QR factorization which is taken into consideration for the first time in the watermarking techniques common side by side with the Lifting Wavelet Transform (LWT). This work investigates the robustness and imperceptibility in the frequency domain. Moreover, in this paper the medical images are adopted to demonstrate the importance of digital image watermarking.

The rest of this paper is organized as follows. In Section 2, basic important information of QR, LWT and chaotic logistic map are covered concisely. Section 3 devoted to present the proposed algorithm. Section 4 of this paper particularized to explain the experimental results and discussion. Finally, the conclusions are documented in Section 5.

2. Preliminaries

This section allocates to provide the receiver basic and important familiar information which will be used in the remainder of this paper.

2.1. QR factorization

Linear algebra supplies image processing by fundamental tools. QR factorization is the best-known method for finding eigenvalues of a general matrix. QR factorization of a matrix is a decomposition of a matrix A into a product of two matrices Q and R such that A=QR, Q is an orthogonal matrix and R is an upper triangular matrix. QR factorization is the basis for a particular eigenvalue algorithm called the QR algorithm (a procedure to calculate the eigenvalues and eigenvectors of a matrix) [7].

Q-operator

- Q is m×n matrix has orthonormal columns such that $Q^TQ = I$.
- If A is a square matrix, i.e. m=n, then Q is orthogonal, i.e. $Q^TQ=QQ^T=I$, where Q^T is the transpose of Q and I is the identity matrix.

R-operator

- R is an n×n upper triangular matrix that has nonzero diagonal.
- R is a nonsingular matrix i.e. the diagonal elements are all nonzero.

2.1.1. QR computation

There are several procedures for factual computation of QR factorization, namely, Gram–Schmidt process, Givens rotations, or Householder transformations. Each has a numeral of advantages and disadvantages [8].

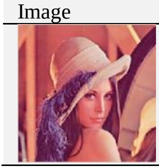
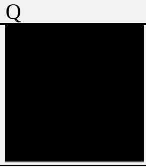
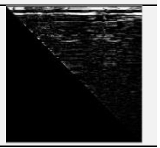
a) Gram-Schmidt orthogonalization, also known as the Gram-Schmidt process. This process is an operation which picks a non-orthogonal set of linearly independent functions and establishes an orthogonal basis on an arbitrary interval.
b) Givens rotations: QR can also be computed via a series of Givens rotations. Each rotation zeroes an element in the subdiagonal of the matrix, forming the R matrix. The chain of all the Givens rotations forms the orthogonal Q matrix.
c) A Householder reflection (or Householder transformation) is a transformation that picks a vector and reflects it about some plane or hyperplane. We can use this procedure to compute the QR factorization of an m-by-n matrix A with m ≥ n.

Table 1 shows the influence of the QR factorization on Lena image using Matlab R2013a (8.1.0.604) environment via [Q,R]=qr(A) code.

2.1.2. Algorithm for QR

1) Use the Gram-Schmidt procedure to find the orthonormal basis of the given vectors that form a basis in the subspace W of the vector space V.
2) Normalize the vectors and use those vectors as the columns to make Q.
3) Solve for the matrix R: $Q^TA = Q^T(QR) = IR = R$.

Table 1: Lena Image Decomposed by QR Factorization

Image	Gray	Q	R
			

2.2. Lifting wavelet transform

Sweldens in [9] introduced the Lifting Wavelet Transform (LWT) depending on the classical wavelet. The LWT has number of advantages compared with the classical wavelet (DWT) because 1- LWT has the ability to compute more efficiently, 2- LWT doesn't need big memory space, 3- LWT has integer coefficients, 4- DWT capable to address the impairment of quantization errors from the classical wavelet transform. Lifting wavelet Transform facilitates the case by immediately analyzing the case in the special domain. The major precept of the LWT is to establish a new wavelet with improved features depend on an easy wavelet that represents the principal key of lifting. LWT turn into a robust scheme for different applications used in image processing: image compression [10], watermarking [11] and pattern recognition [12]. The lifting wavelet transform (LWT) and its inverse transform (ILWT) are of one dimensional (ID) signals. An obvious method to use LWT for two dimensional signals like images is to use row-column (horizontal-vertical) or column-row (vertical-horizontal) passes of the corresponding one-dimensional LWT. Table2 explain the effect of LWT on the grey scale Lena Image. In general, this strategy contains three essential phases:

Splitting: The cover image Im is dismantled into even and odd non-overlapping elements of $\mathrm{Im_e(x)}$ and $\mathrm{Im_o(x)}$.

$$\mathrm{Im_e(x) = Im(2x),\ Im_o(x) = Im(2x+1)} \tag{1}$$

Prediction: In this phase, the value of odd element is predicted using even elements:

$$\mathrm{E(x) = Im_o(x) - P(Im_e(x))} \tag{2}$$

Where $\mathrm{P(.)}$ denote the prediction operator. The prediction phase represents the high pass filtering operation and $\mathrm{E(x)}$ regards the high frequency synthesis which is the error between the original element and its predicted value.

Updating: This phase considered as the lowpass filtering operation and $\mathrm{L(x)}$ regards the low frequency synthesis which shows the coarse approximation to the original image:

$$\mathrm{L(x) = Im_o(x) + U(E(x))} \tag{3}$$

Table 2: The Result of Applying LWT on Lena Image

LL	LH	HL	HH
			

2.3. Logistic map (chaotic case)

The logistic map is a polynomial mapping of degree two, chaotic conduct can expand from candid non-linear dynamical equations [13]. The Logistic map is one of the distinguished one-dimensional chaotic maps. Furthermore, for the randomness of the chaos sequence, the randomness will be better if the sequence length is greater. The mathematical definition of chaotic logistic map with two initial values r and $\mathrm{Logi_0}$ can be expressed as follows:

$$\mathrm{x_{i+1} = rx_i(1 - x_i)} \tag{4}$$

Where $\mathbf{x_i}$ take values in the interval (0, 1), $\mathbf{x_0}$ is the initial value for the sequence and the chaotic parameter $\mathbf{r}$ ∈[3.5699456,4] is a positive constant sometimes known as the biotic potential. Chaotic map is used to fabricate the chaotic sequence and used to control the encoding process [14].

3. Proposed watermarking algorithm

The main execution of the proposed watermarking algorithm can be complemented as three phases: the watermark embedding phase and the watermark extraction phases. The proposed watermark embedding scheme based on QR factorization and LWT is illustrated in Fig. 1. In order to increase the security of the watermarking algorithm, logistic map is used to scramble the blocks.

3.1. Embedding phase

The detailed embedding phase using QR factorization and LWT are explained as follows:

Step1: Input the original image that have size $\boldsymbol{N \times N}$ and convert this image to gray scale image.

Step2: The original image is decomposed by a two-level (LWT).

Step3: Divide the band {LH2} into 2×2 non-over lapping blocks, the number of blocks is $M \times M$.
Step4: Input the watermark image with size $M \times M$ and convert this image to binary image.
Step5: The chaotic logistic map in eq.1 is applied to switch locations of the blocks

$$x_{(i+1)} = r x_i (1 - x_i) \quad (5)$$

Step6: Apply $A = QR$ matrix decomposition to each block.
Step7: Embedding binary watermark bits in R sub matrix produced from step 6

$$R\,(2,2) = R\,(2,2) - R\,(2,2)\,(mod\ S) + T1\ if\ w = 1 \quad (6)$$

$$R\,(2,2) = R\,(2,2) - R\,(2,2)\,(mod\ S) + T2\ if\ w = 0 \quad (7)$$

Where S=20.532 is the single scaling factor which controls the tradeoff between imperceptibility and robustness of the proposed watermarking scheme, T1 = 0.75*S, T2 = 0.25*S.
Step8: Apply reverse operations for $A = QR$and logistic map to get watermarked image.

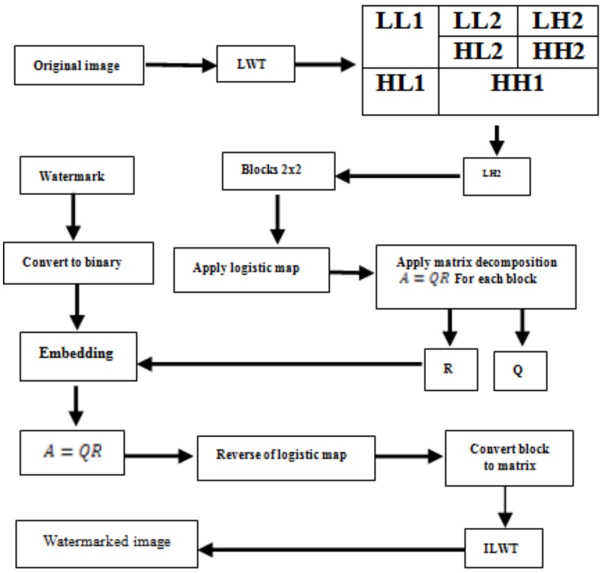


Fig. 1: Block Diagram of Embedding Phase.

3.2. Extracting phase

The detailed extraction phase is illustrated as follows:
Step1: Input the watermarked image with size $N \times N$ and convert this image to grey scale image.
Step2: The watermarked image is decomposed by a two-level (LWT).
Step3: Divide the band {LH2} band into 2×2 non-over lapping blocks, the number of blocks is $M \times M$.
Step4: The chaotic function (logistic map) is applied on a block to restore the blocks to their original locations.
Step5: Apply $A = QR$ matrix decomposition to each block.
Step6: Extraction binary watermark bits from the sub matrix R

$$W = 0 \text{ if mod } (R\,(2,2)) > (T1 + T2)/2 \quad (8)$$

$$W = 1 \text{ if mod } (R\,(2,2)) <= (T1 + T2)/2 \quad (9)$$

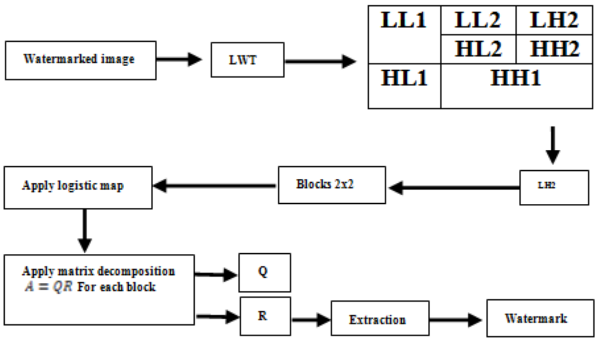
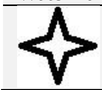
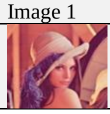
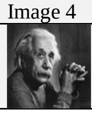


Fig. 2: Block Diagram of Extraction Phase.

4. Experimental results and discussion

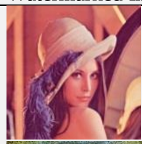
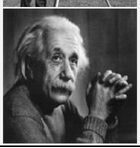
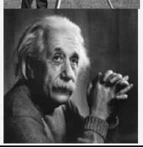
In this section, some experiments are performed to assess the imperceptibility and robustness of the proposed watermarking algorithm. The proposed image watermarking technique is examined with different grayscale cover images of size 512×512. A binary image of size 64×64 is utilized as a watermark image. Table 3 shows the watermark and the images used to test the proposed algorithm.

Table 3: The Watermark and the Images Used to Test the Proposed Algorithm

Watermark	Image 1	Image 2	Image 3	Image 4
				

To evidence the soundness of the proposed watermarking algorithm, some results are clarified. Six sorts of attacks were utilized to test the robustness of the proposed watermarking algorithm. Table 4 demonstrates original images, the watermark image and watermarked images.

Table 4: The Original Images 1, 2, 3 and 4, the Watermark Image W and the Watermarked Images

No	Original image	Watermark W	Watermarked Image
Image 1			
Image 2			
Image 3			
Image 4			

In general, the performances of image watermarking techniques are measured by the robustness, invisibility, computation complexity etc.
PSNR as a good tester for the watermark visibility assess and it is given by the following equation:

$$\text{PSNR} = 10\log_{10}\left(\frac{\text{MAX}^2}{\text{MSE}}\right)$$

Where

$$\mathrm{MES} = \frac{1}{mn}\sum_{i=0}^{m-1}\sum_{j=0}^{n-1}[I(i,j) - K(i,j)]^2$$

And MAX is the maximum grey scale value which here is equal to 256.
The matching between the extracted watermark W′ and the authentic watermark W is computed based on NC (a normalized correlation) between W and W′.

$$\mathrm{NC} = \frac{\sum_i \sum_j w(i,j).w'(i,j)}{\sqrt{\sum_i \sum_j w(i,j)}\sqrt{\sum_i \sum_j w'(i,j)}}$$

The invisibility of the results of the proposed watermarking algorithm is clarified in Table 5, in which the average PSNR and NC values of all watermarked images are listed.

Table 5: The PSNR and NC Values for Watermarked Images without Attacks

Image	Image 1	Image 2	Image 3	Image 4
PSNR	44.161	46.480	44.219	45.016
NC	1	1	1	1

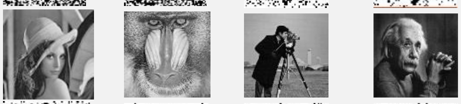
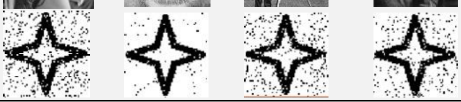
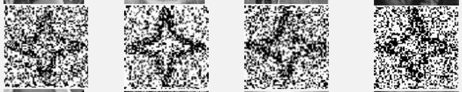
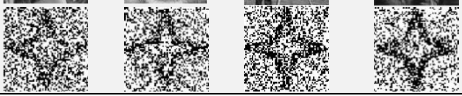
To show the robustness of the proposed mechanism, diverse attacks are implemented on the watermarked image to assess the robustness of the proposed mechanism as shown in Table 6.

Table 6: The PSNR and NC Values for Watermarked Images with Attacks

Attacks	Image 1 PSNR	Image 1 NC	Image 2 PSNR	Image 2 NC	Image 3 PSNR	Image 3 NC	Image 4 PSNR	Image 4 NC
Salt and Pepper %1	27.112	0.909	27.323	0.898	26.769	0.919	26.478	0.907
Imad just	22.290	0.723	19.385	0.624	17.757	0.894	24.800	0.951
JPEG Compression	59.047	0.936	58.604	0,986	59.051	0.949	58.838	0.958
Gaussian Noise	37.679	0.759	37.641	0.818	37.663	0.768	37.654	0.778
Histogram equalization	19.018	0.741	16.471	0.639	19.075	0.656	11.905	0.643
Speckle noise	35.652	0.745	35.513	0.783	35,557	0.773	39.059	0.820

The following are the watermarked images and the extracted watermark image from each one respectively after attacks implementation:

Table 7: Watermarked Images and the Extracted Watermark after Attacks Implementation

Attack Extracted watermark	Image 1	Image 2	Image 3	Image 4
Salt and Pepper %1				
Extracted watermark				
Imad just				
Extracted watermark				
JPEG Compression				
Extracted watermark				
Gaussian Noise				
Extracted watermark				
Histogram equalization				
Extracted watermark				
Speckle noise				
Extracted watermark				

5. Discussion

Two-level LWT added to the 512×512 cover image in the embedding and extracting phases in order to get 4 subbands, LL2, LH2, HL2 and HH2 from the second level, each one is of size 128. The best band chosen in our proposed algorithm is LH2. To make full use of the characteristic of QR factorization that has been illustrated in 2.1, the LH2 band is divided into blocks each one is of size 2×2. This gives 64 blocks, each block run across each bit of the watermark. The logistic map has been used to scrambling the order of the blocks for more security. After that, we applied the QR factorization on each block and modify the R matrix according to the embedding algorithm. The exact core of the proposed watermarking algorithm lies in the features of the extracted matrix R, in which the absolute value of the elements in the first row is greater than the elements of other rows. This importance is concentrated in containing the matrix R the strong properties of the image which lay in the upper of the diagonal. This is exactly the core of the proposed method. Thus the difference between the proposed watermarking algorithm and that one given in [15] is centered on how one chooses the best element for embedding the watermark. Whereas in [15] an optimization method is used to choose the best location for embedding, the watermarking algorithm proposed in this paper gives better results without using optimization.

6. Comparison

This section is devoted to display the strength of the proposed watermarking algorithm comparing with three algorithms given in [15], [16] and [17]. These three algorithms applied to the same images that the proposed watermarking algorithm has been performed on them. Thus, the proposed watermarking method has been comparing in terms of NC values of [15], [16] and [17]. According to the benchmark result, which is shown in Table 8, the proposed method outperformed other works in the shown three attacks. Moreover, the watermark is extracted almost without any damage to information in the proposed scheme.

Table 8: Comparison with NC Values for Watermarked Images with Attacks

Attacks	Proposed method	Ref [15]	Ref [16]	Ref [17]
Salt and Pepper %1	0.909	0.790	0.844	0.903
JPEG Compression	0.986	-	0.974	0.959
Gaussian Noise	0.818	0.687	0.758	0.842

7. Conclusion

In this paper, a new algorithm depending on QR factorization is proposed to secure digital images using Lifting Wavelet transform (LWT). The advantages of the proposed algorithm include: 1- The two levels low-high (LH) band of LWT is chosen to modify the imperceptibility and robustness; 2- Based on the mathematical characteristics of QR factorization, the element in the 2×2 position in each block of LH is adopted as a best location to embed the information of the watermark image; 3- From the experimental results, it is shown that the proposed method can get better PSNRs and that the proposed algorithm fulfils better watermark invisibility and robustness under different attacks. According to equation (6), (7), (8) and (9), the optimum value of coefficients S, T_1 and T_2 is determined based on the compromise between PSNR and NC.

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