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# Fast Watermarking Based on QR Decomposition in Wavelet Domain

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*Abstract*—**A novel blind watermarking technique based on QR decomposition in still images is proposed. The method is implemented in wavelet domain and its robustness has been evaluated against some image processing attacks and the results have been compared with two traditional methods i.e., SVD and DCT. It is shown that while the proposed scheme has low computational complexity, it has better robustness against some image processing attacks in comparison with SVD and DCT methods**

***Keywords- Arnold transformation; copyright protection; QR decomposition; watermarking***

## I. Introduction

Nowadays the growth in internet and digital technology has increased its usage and made it a popular tool to exchange data. Many pictures are shared in websites daily and everyone can use them conveniently. But there will be problem when the shared pictures have significant value. Since everyone who has a copy of original image can claim its ownership, so there must be some methods to preserve the copyright of media like image. Watermarking is one of these methods. Watermarking is the art of invisibly modifying a work such as image, video and audio to embed a data about that work. Digital watermarking methods in still images can be classified in two groups based on the embedding domain: spatial and transform domain. In spatial domain method, a watermark is embedded in the pixels of image. The Least Significant Bit altering algorithm (LSB) is one of the well known examples in this domain. In transform domain, watermarking is based on altering the transform coefficients. Because of weak robustness of spatial domain algorithms in common image processing attacks, transform domain algorithms are preferred.

Another important parameter in watermarking is the location in which the watermark is embedded. Two factors which have important roles in determining this are robustness & imperceptibility of watermark. It is preferred to embed the watermark in most significant coefficients to increase the robustness but this will increase the perceptibility of watermark. On the other hand, embedding watermark in the least significant coefficients helps the imperceptibility of watermark but reduces the robustness. In any case in watermarking, the tradeoff between robustness and imperceptibility must be carefully considered.

Depending on whether the original host image is required or not during the watermark extraction, watermarking techniques can be classified as non-blind, semi-blind, or blind. Non-blind technique requires the original host image to extract the watermark. Semi-blind technique does not require the original host image but depends on some data or feature of original host image to extract the watermark. Blind technique does not require the original host image or any feature of it to extract the watermark.

In this paper we introduce a novel watermarking scheme based on QR decomposition in still images. For evaluation, our scheme is compared with discrete cosine transform (DCT) and singular value decomposition (SVD). As we will see later, our method is faster than the other two algorithms, and has better robustness against some of the image processing attacks including rotation, Salt & pepper noise, Median filtering, and Average filtering. Also, our method has better capacity in comparison with SVD method and adds fewer bits to the watermarked image in comparison with DCT method. The rest of this paper is organized as follow. In section II some related works are introduced. In section III definition to QR decomposition is presented. In section IV our scheme in wavelet domain and its results are introduced and finally in section V conclusions are presented.

## II. Related Works

Several approaches to embed the watermark in host image are considered in papers. Whereas some, e.g. [1], use LSB modification to embed the watermark, others prefer to do watermarking in transform domain for increased robustness. In this way some papers [2]-[5] perform watermarking in SVD domain, while others [6,7] prefer DCT domain and some [8] prefer discrete wavelet transform (DWT) domain to embed the watermark. Also there are improved methods that use combination of these transforms to do watermarking. In [9]-[12] a combination of SVD and DWT, in [13,14] a combination of SVD & DCT, and in [15] a combination of SVD, DCT, and DWT is used to embed the watermark.

Also various methods are examined to embed the watermark in cover image. In [2] singular values and in [3] both singular values and singular vectors are used to embed the watermark. In [5] the order of singular values and in [4] the largest singular value in each 8×8 blocks are used to embed the watermark. In [6] one of the DCT coefficients in each 8×8 blocks based on a threshold value in that block is modified, in [13] the DC values in each 8×8 block and in [14] mid-band DCT coefficients are modified to embed the watermark. In [7] the effect of modifying various DCT

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coefficients is proposed and their robustness is evaluated. In [10] all DWT sub-bands are used whereas in [11] high-pass sub-bands and in [12] low-pass sub-band are used to embed the watermark.

## III. QR Decomposition

In QR decomposition any matrix can be represented as:

$$\boldsymbol{A} = \boldsymbol{QR} \tag{1}$$

where $\boldsymbol{Q}$ is an $m \times n$ matrix with orthonormal columns and $\boldsymbol{R}$ is an $n \times n$ upper triangular matrix. In this method columns of $\boldsymbol{Q}$ is created from columns of $\boldsymbol{A}$ by Gram-Schmidt process. If we show $\boldsymbol{A}$ and $\boldsymbol{Q}$ respectively as $\boldsymbol{A} = [\boldsymbol{a}_1 \quad \boldsymbol{a}_2 \quad \ldots \quad \boldsymbol{a}_n]$, $\boldsymbol{Q} = [\boldsymbol{q}_1 \quad \boldsymbol{q}_2 \quad \ldots \quad \boldsymbol{q}_n]$ in which $\boldsymbol{a}_i$ and $\boldsymbol{q}_i$ are column vectors, then the matrix $\boldsymbol{R}$ can be computed as:

$$\boldsymbol{R} = \begin{bmatrix} \langle \boldsymbol{a}_1, \boldsymbol{q}_1 \rangle & \langle \boldsymbol{a}_2, \boldsymbol{q}_1 \rangle & \cdots & \langle \boldsymbol{a}_n, \boldsymbol{q}_1 \rangle \\ 0 & \langle \boldsymbol{a}_2, \boldsymbol{q}_2 \rangle & \cdots & \langle \boldsymbol{a}_n, \boldsymbol{q}_2 \rangle \\ \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & 0 & \langle \boldsymbol{a}_n, \boldsymbol{q}_n \rangle \end{bmatrix} \tag{2}$$

Where $\langle \ \rangle$ means the inner product. In other words, in this way a new orthonormal basis (columns of $\boldsymbol{Q}$) for an $n$ dimension vector space are set up by means of columns of $\boldsymbol{A}$ and Gram-Schmidt process, then the projection of columns of $\boldsymbol{A}$ to new basis vectors, produces elements of $\boldsymbol{R}$.

One of the good properties of $\boldsymbol{R}$ matrix which has been used in our scheme is that when the columns of $\boldsymbol{A}$ have correlation with each other as in our case, absolute value of the elements of the first row of $\boldsymbol{R}$ matrix are probably greater than the absolute value of the other rows. Also, in QR decomposing the uniform regions of picture where the columns of 8×8 blocks are the same, only the first row of $\boldsymbol{R}$ matrix has value and others are nearly zero. So if we select other rows to embed the watermark, there will be significant visual perception in the watermarked image which is not suitable. So we have used the first row of $\boldsymbol{R}$ matrix to embed the watermark in our scheme.

## IV. Watermark Embedding & Extracting

In this section our proposed scheme in wavelet domain is presented. To evaluate our scheme, we have compared it with DCT and SVD, two known methods in watermarking. To evaluate the performance of the proposed algorithm, a similarity measure between the original watermark $w$ and the extracted watermark $w'$ is computed by using the normalized correlation (NC) as:

$$NC = \frac{\sum_{\text{All i}} w_i w_i'}{\sum_{\text{All i}} w_i^2}, \quad w_i, w_i' \in \{-1, 1\}. \tag{3}$$

Also, the quality of the watermarked and original image are measured based on the peak signal to noise ratio (PSNR) which is defined by:

$$PSNR = 20 \log_{10} \frac{255}{\sqrt{MSE}} \tag{4}$$

Where mean square error (MSE) is defined as the square of error between the original and watermarked image by:

$$MSE = \frac{1}{N \times N} \sum_{\text{All i}} \sum_{\text{All j}} \left[ I_{\text{O}}(i,j) - I_{\text{W}}(i,j) \right]^2 \tag{5}$$

where $N \times N$ is the image size, $I_{\text{O}}$ original image, and $I_{\text{W}}$ watermarked image.

### A. Proposed Scheme

In this scheme we intend to embed a binary image as watermark into a grayscale image. Since our data is digital, this scheme can be applied to any other digital data. Our selected watermark is an 88×88 logo and it is encrypted by cat map in two steps to be more secure and provide large key space like the scheme which is presented in [16]. In our scheme, we have 8 places in the first row of $\boldsymbol{R}$ matrix in each 8×8 block to embed the encrypted watermark bits. The watermark embedding method is as follow:

1. One-level 2D discrete wavelet transform (2D-DWT) using Haar filter is applied to the cover image.
2. LL sub-band is divided into 8×8 non-overlapping blocks.
3. QR decomposition is applied to each 8×8 blocks.
4. First row of $\boldsymbol{R}$ matrix in each block is selected to embed the encrypted watermark using (6).

$$\begin{cases} C' = C - (C \bmod S) + T_1, & \text{if} \quad w = 1 \\ C' = C - (C \bmod S) + T_2, & \text{if} \quad w = 0 \end{cases} \tag{6}$$

Where $C$ is the selected coefficient to embed the watermark bit, $C'$ is the changed coefficient, $S$ is the watermarking strength and $T_1$ & $T_2$ are threshold values. In [8] it has been shown that selecting $T_1$=3$S$/4 and $T_2$=$S$/4 provides good robustness against JPEG compression. We have used these values for watermarking.

5. Inverse QR decomposition is applied.
6. Inverse DWT is applied.
7. A regulation is performed to limit the value of pixels between 0, 255 as in grayscale images.

The watermark extracting procedure is as follow:

1. One-level 2D discrete wavelet transform (2D-DWT) using Haar filter is applied to the watermarked image.

2. LL sub-band is divided into 8×8 non-overlapping blocks.
3. QR decomposition is applied to each 8×8 blocks.
4. Encrypted and possibly attacked watermark is extracted from the first row of ***R*** matrices using (7).

$$\begin{cases} w'=1, & \text{if} \quad (C'' \bmod S) > (T_1+T_2)/2 \\ w'=0, & \text{if} \quad (C'' \bmod S) < (T_1+T_2)/2 \end{cases} \quad (7)$$

Wherein $w'$ is the extracted watermark and $C''$ is the watermarked coefficient after possible attacks. As seen from (7) our scheme is a blind one and do not need cover image to extract the watermark.

5. Watermark is decrypted.

The block diagram of proposed scheme is depicted in Fig. 1.

For evaluating our scheme SVD and DCT transforms are replaced with QR in Fig. 1. To be fair, in SVD method only the 1st singular value in each 8×8 block and in DCT method 8 low frequency coefficient in each 8×8 block as shaded in Fig. 2 are selected to embed the watermark. In [7] DCT coefficients are divided to 3 groups, DC, low and mid frequency and it has been proposed that the low frequency coefficients are good choice as a tradeoff between robustness and imperceptibility to embed the watermark. Hence in this case watermarking capacity of SVD method is 1/8 of the watermarking capacity of DCT and QR methods

We have selected ten 512×512 pixel grayscale cover images and a digital logo as in Fig. 3 for watermarking and the results which are depicted in tables are averaged results. The size of digital logo for SVD method is 32×32 and for DCT and QR methods is 88×88. The watermarking strength is fixed at $S$=32.

First no attack is considered on watermarking system and for evaluation resultant PSNR values of three systems are

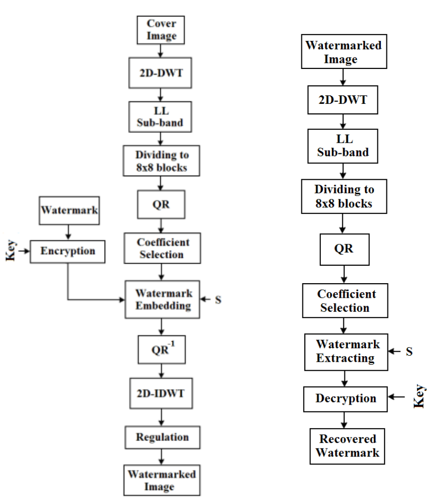



Figure 1. Watermark Embedding and Extracting block diagrams.

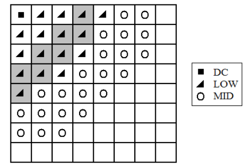



Figure 2. Selected DCT coefficients to embed the watermark in an 8×8 block [7].

Figure 3. Scaled Original watermark.

compared to each other. In this case as seen from TABLE I SVD is near 9 dB better than DCT and QR methods, but it must be considered that SVD method has the 1/8 watermarking capacity of the other two methods.

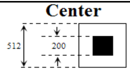
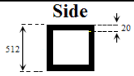
At the next step some image processing attacks are performed on three systems and resultant NC values are compared to each other in TABLE II. In Center-crop a 200×200 pixel square is cropped from the center of watermarked image and in Side-crop a 20 pixel narrow band is cropped from the sides of watermarked image. As seen from TABLE II in this case QR and DCT have near results and both of them are better than SVD. Also, this is noticeable in rotation attack. In Gaussian filtering and scaling attacks, SVD and DCT have near results and are better than QR method. In Average filtering, Median filtering and Salt & pepper noise QR method has very good results in comparison with the other two methods.

Finally in this section we have compared the speed of three methods. As seen from TABLE I, QR method is the fastest among the three methods and SVD is somewhat slower than QR and DCT is the slowest one from the computational complexity point of view. To evaluate the speed of three methods, the time of 100 successive watermarks embedding and extracting for each method is measured and it is illustrated in TABLE I. The platform on which these results are measured is a P4, 2.80GHZ CPU, 1.25GB RAM, XP SP3, MATLAB 7.6.0 (R2008a). Also, we have examined the added bits to the watermarked images. To do this we tested watermarking on 30 images and compared the result of three methods in TABLE I. As seen from this table QR in comparison with DCT, which both have the same watermarking capacity in our scheme, adds fewer bits to the original image. In this table SVD has the least added bits because of its low watermarking capacity.

TABLE I. COMPARISON OF THREE METHODS

| Comparison \ Method | QR | SVD | DCT |
|---|---|---|---|
| ***PSNR (dB)*** | 41.62 | 50.44 | 41.19 |
| ***Time (s)*** | 146 | 160 | 377 |
| ***Added bits (%)*** | 0.2 | 0.02 | 0.46 |

TABLE II. NC COMPARISON OF THREE METHODS AT FIXED WATERMARKING STRENGTH (*S*=32) IN PRESENCE OF DIFFERENT ATTACKS

| Attack | | QR | DCT | SVD |
|---|---|---|---|---|
| No Attack | | 1 | 1 | 1 |
| *Filtering* | Median 3×1 window | 0.9090 | 0.8568 | 0.7562 |
| | Average 3×1 window | 0.9076 | 0.7496 | 0.8125 |
| | Gaussian 3×3 window $m=0, \sigma=0.5$ | 0.8729 | 0.9420 | 0.9021 |
| *Noise* | Salt & pepper 0.005 | 0.8074 | 0.4028 | 0.2916 |
| | Gaussian $m=0, \sigma=0.01$ | 0.9837 | 0.9954 | 0.8822 |
| *Scaling* | 25% maximize | 0.9731 | 0.9957 | 0.9923 |
| | 25% minimize | 0.8524 | 0.9475 | 0.9572 |
| *Crop* | **Center**  | 0.7318 | 0.7327 | 0.7193 |
| | **Side**  | 0.7528 | 0.7551 | 0.6466 |
| *Rotation* | 5 Degree | 0.8596 | 0.8528 | 0.7724 |
| | 10 Degree | 0.7519 | 0.7286 | 0.6103 |
| *JPEG Compression* | Quality factor 37.5% | 0.9879 | 0.9708 | 0.9964 |
| | Quality factor 50% | 0.9983 | 0.9926 | 0.9964 |
| | Quality factor 75% | 0.9998 | 1 | 0.9964 |

## V. CONCLUSION

In this paper we have presented a novel blind watermarking technique to embed a binary image as watermark in a grayscale image. The scheme is based on QR decomposition and uses ***R*** matrix to embed the watermark. Also, it has low computational complexity while maintaining the robustness against different image processing attacks. The watermarking scheme is done in transform domain and introduces good results in comparison with two traditional methods SVD and DCT. The summaries of results are as follows:

- Our method has the lowest and DCT method has the highest computational complexity (running time). Also, QR adds fewer bits to watermarked image in comparison with DCT which the same watermarking capacity is considered for both of them. Also, QR has greater watermarking capacity toward SVD.
- In evaluating robustness against some image processing attacks, in some cases our method has advantages over DCT and SVD methods. Especially, against rotation, Median filtering, Average filtering and Salt & pepper noise.

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