Robust Imperceptible Gray Image Watermarking with LWT, SVD and QR Decomposition

Sushama Agrawal and Anjali Bhalchandra

***Abstract*—This work suggests a unique watermarking technique based on QR decomposition and singular value decomposition (SVD) in the lifting wavelet transform (LWT) domain. It's a hybrid watermarking method working on LWT's energy compaction property with a combination of QR and SVD to enhance watermarking performance. The image is decomposed with three levels of LWT, then QR factorization on CH3 subband and finally SVD is applied to R matrix. Watermark is scrambled using Arnold transform (AT) to improve security aspect. Singular values are modified with scaling factor and watermark bit. Robustness and imperceptibility are important parameters in image watermarking. Proposed technique combats trade-off between robustness and imperceptibility for varying watermark embedding strength. It also withstands attacks like image processing, noising, filtering, compression, geometric. Performance is evaluated with PSNR, SSIM, BER and NCC.**

***Index Terms*—Imperceptibility, lifting wavelet transform, QR decomposition, robustness, SVD.**

I. Introduction

Over time, as internet, digital communications and media transmission have grown in popularity, undesirable activities such as fabrication, alteration, imitation and others have increased. The authentication, ownership and copyright protection of audio, visual, textual or other data is a serious issue. In today's digital age, it is a crucial issue that requires immediate attention. Digital image watermarking [1] is a typical method for protecting data. Watermark detection requirements are used to classify existing watermarking systems. As a result, three techniques exist: blind, semi-blind and non-blind. The host image or any part of it is not necessary for blind watermark detection, part of host image is required for semi-blind and entire image for non-blind. The most important characteristics of good watermarking technique are imperceptibility, robustness, security and capacity. Imperceptibility is a requirement that is important in all watermarking applications and not only in copyright protection applications. In practice, the requirement of imperceptibility implies that the perceptual quality of the watermarked data in the case of digital images should be kept high. The idea behind watermarking is to create a translucent image on the paper to provide authenticity. The visual similarity between the original and the generated information after watermarking is known as imperceptibility. A technique is robust if it can resist attacks i.e., watermark can be recovered from an attacked image [2]. Capacity is the largest quantity of information that can be inserted in image without generating image degradation. But robustness, imperceptibility and capacity are parameters which conflict with each other [3]. Existing watermarking techniques are classified in to spatial and spectral domain. Spatial domain [4]-[6] techniques have advantage of less complexity and good imperceptibility but suffer from weak robustness. Watermarks are frequently inserted using spectral-domain techniques such as the Discrete Cosine Transform (DCT), Discrete Wavelet Transform (DWT), Lifting Wavelet Transform (LWT), Fast Fourier Transform and many more. Nowadays, hybrid techniques using combinations like DWT SVD, LWT SVD, LWT DCT SVD are also extensively used.

SVD has been widely employed for embedding data in both the spatial and transform domains [7]-[11] which makes scheme robust to many attacks. Lai and Tsai [12] used an algorithm to embed grey level bits into singular values of the host image in the wavelet domain for reducing computational complexities. Blind scheme using signature-based authentication to avoid false positive detection proved to be far better in performance against all attacks including print and scan attacks [13]. Makbol *et al.* [14] used combination of Integer Wavelet Transform (IWT) and SVD to get robust, imperceptible scheme. Further, security aspect was enhanced by adopting digital signature into watermarked image. Mayank Awasthi [15] used DWT, DCT and SVD claiming that approach is more robust against JPEG compression, Gaussian blur, salt and pepper noise, rotation with cropping giving high values of Peak Signal to Noise Ratio (PSNR) and correlation coefficient. Jun Yun *et al.* [16] combined chaotic maps with DWT, DCT and SVD. The spatial frequency localization properties of DWT, the energy collection characteristics of DCT and the stability aspects of SVD makes the technique imperceptible and robust.

QR, LU, Schur, and Cholesky matrix decompositions are used to embed watermark in transform domain. A technique in DWT QR domain inserts watermark bits in R matrix through quantization [17]. It resulted in an improved performance against few attacks. A spatial domain technique uses pseudorandom circular chain for random selection of watermarking blocks to improve security [18]. A unique watermarking technique is proposed using a mix of LWT, QR with Lagrangian support vector regression (LSVR). LWT-QR decomposition combination resulted in improved imperceptibility and high generalization property of LSVR led to better robustness [19]. Guo and Li proposed a technique based on Linear Canonical Wavelet Transform and QR decomposition making it robust to image processing attacks and geometric attacks [20]. Areej and Hamid [21] suggested an approach in LWT and QR domain making the technique imperceptible to a limited extent and robustness is also good

Manuscript received January 15, 2022; revised June 23, 2022.

Sushama Agrawal and Anjali Bhalchandra are with the Electronics department, Government College of Engineering, Aurangabad, Maharashtra, India (e-mail: ssa_etx@geca.ac.in, asbhalchandra@gmail.com).

DOI: 10.7763/IJCTE.2022.V14.1315

against very few attacks. Watermarking techniques for colour images with QR factorization are discussed in [22]-[27]. Algorithms [17]-[21] are either in spatial domain or in single level transform domain which divided the image into blocks and embedded watermark bits in each block. It requires that number of blocks must be at least equal to watermark size. Above mentioned techniques are not resistant to all types of attacks and hence considering these drawbacks, a semi-blind watermarking algorithm based on combination of LWT, QR and SVD is being proposed that is robust and undetectable for a wide range of scaling factors.

The rest of the paper is planned along these lines: Section II briefly describes preliminary works used in this paper. Section III explains watermark embedding and extraction algorithms. Section IV discusses experimentation analysis to indicate the performance of the suggested technique. Finally, in Section V the conclusions are presented.

II. Preliminary Works

A. Lifting Wavelet Transform

Sweldens [28] introduced LWT known as the second-generation wavelet, as a replacement for DWT. Convolution procedures are replaced by simple operations such as addition, subtraction and averaging, eliminating the requirement for many additions and multiplications. As a result, computational performance improves and memory use decreases. Split, predict and update are the three operations that make up a lifting stage. These operations are repeated for rows as well as columns to get single level LWT giving subbands CA, CV, CH and CD for approximate, vertical, horizontal and detail coefficients respectively. LWT has a high energy compaction rate, aids in the implementation of a strong watermarking technique [29].

B. QR Factorization

QR factorization [17]-[19], [23] known as orthogonal triangular decomposition of matrix P is represented as:

$$P_{mxn} = Q_{mxm}R_{mxn} \qquad (1)$$

where R is an $m\ x\ n$ upper triangular matrix with nonzero diagonal elements, Q is a mxm unitary matrix with orthonormal columns ($Q^TQ = QQ^T = I$). Columns of Q are obtained with Gram Schmidt orthogonalization [18] process which helps to resist attacks. First column elements in orthogonal matrix Q are very near to each other. R matrix has an essential property that the absolute values of elements in the first row are bigger than those in the remaining rows, implying that the first row contains maximum energy [17], [19].

C. Singular Value Decomposition

SVD, a mathematical transformation widely used for factorization of a real or complex matrix with diverse applications in image processing. *SVD* decomposes matrix into three matrices *U*, *S* and *V*

$$USV^T = svd(X) \qquad (2)$$

where *X* - *n x n* matrix,

U, *V* - orthogonal matrices, *S* - singular diagonal matrix

It is represented as:

$$[U\ S\ V^T] = \begin{bmatrix} u_{11} & u_{12} & \cdots & u_{1n} \\ u_{21} & u_{22} & \cdots & u_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ u_{n1} & u_{n2} & \dots & u_{nn} \end{bmatrix} \begin{bmatrix} \lambda_1 & 0 & \dots & 0 \\ 0 & \lambda_2 & \dots & 0 \\ \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & 0 & \lambda_n \end{bmatrix} \begin{bmatrix} v_{11} & v_{12} & \cdots & v_{1n} \\ v_{21} & v_{22} & \cdots & v_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ v_{n1} & v_{n2} & \dots & v_{nn} \end{bmatrix}^T = \sum_{i=1j=1}^{n} u_{ij}\lambda_j v_{ij}^T \qquad (3)$$

S=diagonal (λ_i) consisting of diagonal elements $\lambda_1, \lambda_2, \lambda_3 \dots \dots \dots . \lambda_n$ are in descending order. Columns of *U* and *V* are left and right singular vectors respectively.

D. False Positive Detection

SVD based image watermarking schemes suffer from a problem of false positive detection (FPD) [30]-[32]. Arnold Transform (AT) is incorporated with secret key '*n*' to avoid FPD. Experimentations carried out using two other watermarks with different values of key '*n*' have shown LWT, QR and SVD is comparatively less susceptible to false positive detections.

III. Proposed Scheme

A watermarking technique based on LWT, QR and SVD is proposed. Host image is decomposed to third level using Haar wavelet. Selection of Haar wavelet is based on maximum PSNR. CH3, CV3 and CD3 subbands contain detailed information whereas low resolution information is in the CA3 subband. Selection of correct subband for embedding watermark play a key role in performance of watermarking technique. CA3 and CD3 subband performance in presence of attacks is questionable. CA3 gives robustness against attacks but poor imperceptibility. CD3 has problems specifically for compression attack. Therefore, CH3 and CV3 are preferred for watermarking. Watermark is scrambled using Arnold Transform [33]. QR decomposition of selected subband gives Q and R matrices. The absolute values of elements in first row of the R matrix are greater than elements in the other rows indicating maximum energy concentration [19]. It increases the modification range without affecting image properties. The R matrix is decomposed using SVD and the watermark is embedded in singular values with a scaling factor. Singular values do not change significantly even after attacks so watermark can be extracted with good correlation coefficient and minimum error rate. The combination of QR and SVD gives scope to alter singular values over a wider range. Major drawback for SVD is computational complexity but decomposition of host image using three level LWT reduces size of subbands. SVD is performed on these subbands which leads to smaller number of computations.

A. Watermark Embedding

Host image *X* and watermark *W* of size 256 x 256 and 32 x 32 respectively are selected for watermark insertion and security key is '*n*'. Embedding algorithm is explained as below:

1) Host Image is decomposed to the third level using the Haar wavelet.
2) Watermark is scrambled using AT with key '*n*'.
3) CH_3 subband is chosen for watermarking. *QR* decomposition is applied to subband to get *Q* and *R* matrices.

4) *SVD* to *R* matrix gives three matrices *U*, *S* and *V*.

$$USV^T = svd(R) \quad (4)$$

5) Watermark is embedded in *S* matrix with scaling factor α to get S_1.

$$S_1 = (S + \propto W) \quad (5)$$

6) *SVD* is applied on S_1 to get watermarked singular values S_w.

$$U_w S_w V_w = svd(S_1) \quad (6)$$

7) Inverse *SVD* is applied on S_w to get watermarked *R* matrix

$$R_w = U * S_w * V \quad (7)$$

8) New watermarked subband $CH3_w$ is obtained with inverse QR decomposition
9) Watermarked image X_w is reconstructed by applying three level inverse *LWT* using Haar wavelet

B. Watermark Extraction

Watermark is retrieved using key '*n*' and three matrices U_w, V_w *and* S_w from the embedding algorithm.

1) Three level LWT decomposition on watermarked image gives $CA3_{wm}, CD3_{wm}, CH3_{wm}$ and $CV3_{wm}$ subbands.
2) *QR* decomposition is applied to $CH3_{wm}$ subband to get *Q* and *R* matrices.
3) *SVD* to *R* matrix gives singular values required for watermark extraction.

$$U_e S_e V_e^T = svd(R) \quad (8)$$

4) Inverse *SVD* is applied to U_w, S_e and V_w to get S_{wm} matrix.
5) Watermark bits are extracted using these new singular values as well as old values.

$$W_n = (S_{wm} - S_w)/\alpha \quad (9)$$

6) Inverse AT is applied to reconstruct watermark.
7) Different performance parameters are computed using the same.

IV. Experimental Analysis

For experimental analysis, USC SIPI image database are used [18], [34], [35] and proposed scheme is implemented using MATLAB R2020b platform. Six standard benchmark images "Lena", "Cameraman", "Baboon", "Peppers", "Pirate" and "Living Room" and binary watermark "SA" shown in Fig. 1 are used for experimentations and performance evaluation. Embedding and extraction of watermark is implemented as mentioned in previous section.

PSNR, Structural Similarity Index Measure (SSIM), Bit Error Rate (BER) and Normalized Correlation Coefficient (NCC) are used for performance evaluation [35], [36]. PSNR, *SSIM* are used to ascertain watermarked image imperceptibility. *PSNR* is a metric that compares the visual integrity of the host and watermarked images. For enhanced transparency, higher *PSNR* values are preferred. SSIM evaluates picture quality degradation [35], [36]. The robustness of the watermarking technique is measured using *NCC* and *BER* between watermark and extracted watermark.

A. Performance Evaluation Parameters

Metric assessment parameters [35]-[37] for measuring the performance are defined as:

$$PSNR = 10 * \log_{10}\left(\frac{255^2}{MSE}\right) \quad (10)$$

where

$$MSE = \frac{\sum_{i=1}^{M}\sum_{j=1}^{N}[X(i,j) - X_w(i,j)]^2}{M*N} \quad (11)$$

where host (X) and watermarked image (X_w) have a size *M X N*.

$$SSIM(x,y) = \frac{(2\mu_x\mu_y + k_1)(2\sigma_{xy} + k_2)}{(\mu_x^2 + \mu_y^2 + k_1)(\sigma_x^2 + \sigma_y^2 + k_2)} \quad (12)$$

where $k_1 = (0.01*L)^2$, $k_2 = (0.03*L)^2$

L = dynamic range of the images
μ_x, μ_y = means of two images
σ_x, σ_y = standard deviations
σ_{xy} = covariance

NCC and *BER* are defined as follows:

$$NCC = Corr(W, W') = \frac{\sum_i\sum_j W_{ij}W'_{ij}}{h\ X\ w} \quad (13)$$

$$BER = \frac{Number\ of\ error\ bits}{Size\ of\ watermark} = \frac{B}{h\ X\ w} \quad (14)$$

where W_{ij} and W'_{ij} values at (*i*, *j*) for original and extracted watermark respectively; *h*, *w* are height and width of watermark. *BER* is the ratio of mismatched bits to the total number of bits in the initial and extracted watermark.

B. Imperceptibility Assessment

Six different images are used as cover images are shown in Fig. 1 (a) to (f). Watermark is shown in Fig. 1 (g). Watermarked images with extracted watermarks are represented in Fig. 2 (a) to (f).

Fig. 1. Standard benchmark images and watermark (a) Lena (b) Cameraman (c) Living room (d) Mandril (e)Peppers (f) Pirate (g) watermark.

Results of PSNR, SSIM, NCC and BER values without any attack of watermarked image are shown in Table I. PSNR values are more than 50 and SSIM is almost '1' indicates good imperceptibility. Similarly, NCC is above 0.97 for images and BER lies in the range of 0.0039 to 0.0078 indicating that its robustness is also good.

Scaling factor determines the strength of watermark embedding in the host image as a result, influences the robustness and imperceptibility. While embedding the watermark, the scaling factor is raised in 0.02 increments. Effect of change of scaling factor on performance of technique is verified on one of the image LENA. Results for parameters are shown in Table II. Almost all existing techniques show a trade-off between robustness and imperceptibility, i.e., as scaling factor increases, robustness improves but watermarked image quality degrades. But a combination LWT, QR and SVD help us to overcome this limitation.

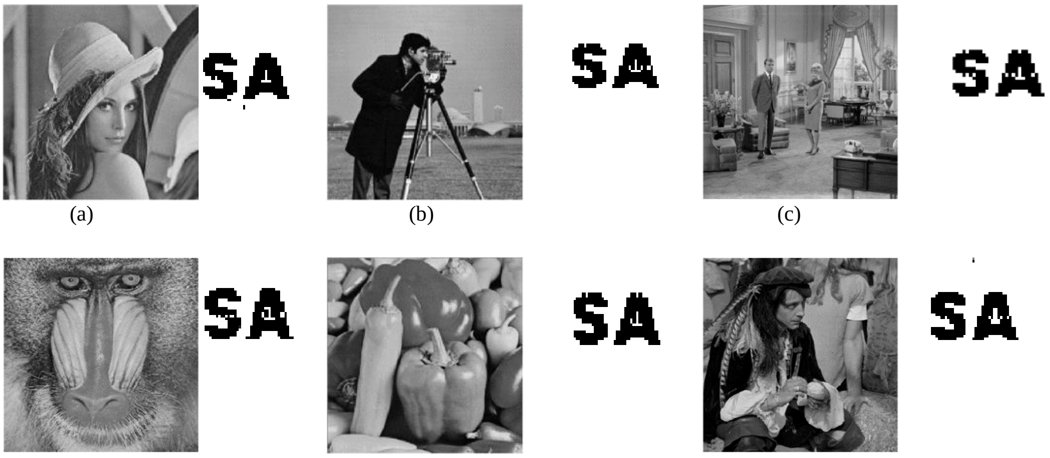
(a) (b) (c) (d) (e) (f)

Fig. 2. Watermarked images with extracted watermarks (a) Lena (b) Cameraman (c) Living room (d) Mandril (e) Peppers (f) Pirate.

TABLE I: IMPERCEPTIBILITY AND ROBUSTNESS ASSESSMENT WITH PSNR, SSIM, BER, NCC WITHOUT ANY ATTACKS

Parameters	Lena	Cameraman	Living Room	Peppers	Baboon	Pirate
PSNR	53.0368	53.4227	53.4042	53.2155	53.6096	53.3494
SSIM	0.9992	0.9988	0.9994	0.9991	0.9997	0.9990
BER	0.0039	0.0049	0.0078	0.0039	0.0078	0.0039
NCC	0.9887	0.9858	0.9773	0.9858	0.9773	0.9887

TABLE II: PSNR, SSIM, BER AND NCC VALUES WITH DIFFERENT SCALING FACTORS FOR TEST IMAGE LENA

Scaling Factor	PSNR	SSIM	BER	NCC
0.01	53.0948	0.9992	0.0059	0.9887
0.03	53.0687	0.9992	0.0059	0.9887
0.05	53.0431	0.9992	0.0068	0.9830
0.07	53.0499	0.9992	0.0068	0.9830
0.09	53.0308	0.9992	0.0059	0.9830
0.11	53.0312	0.9992	0.0068	0.9830
0.13	53.0372	0.9992	0.0078	0.9830
0.15	53.0372	0.9992	0.0068	0.9830
0.17	53.0571	0.9992	0.0059	0.9858

C. Robustness Assessment

Quality of watermark extracted from attacked watermarked images indicates robustness of proposed algorithm. It is quantified using BER and NCC between original watermark and extracted watermark. Several filtering attacks like median, average, Gaussian, Wiener; noising attacks like Poisson, salt and pepper, Speckle, Gaussian; image processing attacks like Gamma correction, histogram equalization, motion blurring, sharpening and geometric attacks like scaling, cropping, rotation, JPEG compression have been employed to assess robustness.

Attacks mentioned above are carried out on three different types of images Lena, Baboon and Pirate. NCC, BER results are indicated in Table III and IV and it shows that these parameters are having values more than 0.9 and less than 0.03 respectively for almost all attacks. NCC values are less than 0.9 but greater than 0.8 and BER slightly higher for few attacks like cropping, motion blur and rotation. Fig. 3 shows the attacked watermarked image and corresponding extracted watermarks.

Median Filter 3x3 Median Filter 4x4 Gaussian Filter 3x3 Wiener Filter

Fig. 3. Attacked watermarked images and extracted watermarks.

A. *Comparative Analysis*

The performance of the proposed method is compared with the techniques used by Yashar [17], Song Wei [18] and Mehta [19]. NA is indicated in the table wherever the result for concerned image is not given in the paper being referred.

These techniques have used QR factorization in wavelet domain [17], in spatial domain [18] and in wavelet domain using LSVR [19]. PSNR, NCC and BER are used for comparison and results are presented. PSNR of proposed technique is compared with existing techniques and results are tabulated in Table V. PSNR is more than 50 which is significant improvement as compared for techniques implemented in [17]-[19] Comparative analysis of present technique for two parameters NCC and BER is presented in Table VI, VII and VIII for various types of signal processing attacks, noising attacks, filtering attacks and geometric attacks. NCC comparison of proposed technique with [17] is presented in Table VI. Correlation coefficient between extracted watermark and original watermark being more than 0.9 for most of the attacks as compared to [17] indicates robustness of high level. Comparison of same parameters with Song [18] is presented in Table VII and the results are exceedingly better barring a few. Table VIII shows the comparison of proposed algorithms in terms of BER with [19]. BER is comparatively reduced for most of the attacks.

TABLE III: NCC OF THE PROPOSED SCHEME FOR THREE IMAGES LENA, BABOON AND PIRATE

Attacks	**NCC**		
	Lena	**Baboon**	**Pirate**
No attack	0.9858	0.9773	0.9887
Median Filter (3x3)	0.9509	0.9241	0.9432
Median Filter (4x4)	0.9339	0.9196	0.9141
Gaussian Filter (3x3)	0.9590	0.9450	0.9509
Wiener Filter	0.9453	0.9161	0.9306
Average Filter (3x3)	0.9326	0.9026	0.9232
Salt & Pepper Noise (0.01)	0.9774	0.9573	0.9660
Speckle Noise	0.9687	0.9659	0.9744
Gaussian Noise	0.9659	0.9716	0.9524
Poisson Noise	0.9659	0.9716	0.9688
Histogram Equalization	0.9688	0.9688	0.9659
Gamma Correction (0.9)	0.9723	0.9604	0.9716
Sharpening	0.9688	0.9630	0.9773
Intensity Transformation	0.9830	0.9716	0.9716
Scaling 256 to 512 to 256	0.9915	0.9716	0.9830
Shifting	0.9858	0.9773	0.9887
Cropping	0.8996	0.9461	0.9301
Motion Blur	0.9064	0.8832	0.8478
Compression Q = 37.5	0.9688	0.9773	0.9688
Rotation 0.01°	0.9374	0.9460	0.9287
Rotation 5 °	0.8939	0.8668	0.9271
Rotation -5 °	0.9139	0.8970	0.9487

TABLE IV: BER OF THE PROPOSED SCHEME FOR THREE IMAGES LENA, BABOON AND PIRATE

Attacks	**BER**		
	Lena	**Baboon**	**Pirate**
No attacks	0.0049	0.0078	0.0039
Median Filter (3x3)	0.0176	0.0273	0.0205
Median Filter (4x4)	0.0234	0.0293	0.0313
Gaussian Filter (3x3)	0.0146	0.0195	0.0176
Wiener Filter	0.0195	0.0303	0.0254
Average Filter (3x3)	0.0244	0.0361	0.0283
Salt & Pepper Noise 1%	0.0078	0.0146	0.0117
Speckle Noise	0.0107	0.0117	0.0088
Gaussian Noise	0.0117	0.0098	0.0166
Poisson Noise	0.0117	0.0098	0.0107
Histogram Equalization	0.0107	0.0107	0.0117
Gamma Correction (0.9)	0.0098	0.0137	0.0098
Sharpening	0.0107	0.0127	0.0078
Intensity Transformation	0.0059	0.0098	0.0098

Scaling 256 to 512 to 256	0.0029	0.0098	0.0059
Shifting	0.0049	0.0078	0.0039
Cropping	0.0361	0.0186	0.0254
Motion Blur	0.0352	0.0439	0.0596
Compression (QF =37.5)	0.0107	0.0078	0.0107
Rotation 0.01°	0.0215	0.0186	0.0254
Rotation 5 °	0.0361	0.0449	0.0264
Rotation -5 °	0.0293	0.0352	0.0176

TABLE V: IMPERCEPTIBILITY COMPARISON OF PROPOSED METHOD WITH EXISTING METHODS

Images	Proposed	[19]	[17]	[18]
Lena	54.7694	45.9283	41.62	44.43
Peppers	54.8514	45.9020	NA	NA
Elaine	54.5202	45.6751	NA	NA
Baboon	54.7060	44.0758	NA	40.05
Cameraman	54.6136	NA	NA	NA
Living Room	54.9262	NA	NA	NA
Boat	54.5202	45.5737	NA	NA
Airplane	55.1090	45.5737	NA	42.74
Pirate	54.4703	NA	NA	NA

TABLE VI: NCC VALUE COMPARISON WITH YASHAR *ET AL*. [17] METHOD FOR "LENA" IMAGE

Attacks		[17]	Proposed Method
No Attack		1	0.9831
Filtering	Median 3x1	0.9090	0.9381
	Average 3 x1	0.9076	0.9306
	Gaussian 3x3	0.8729	0.9479
Noising	SPN density = 0.5%	0.8074	0.9636
	GN m=0, σ=0.01	0.9837	0.9659
Scaling operations	25% maximize	0.9731	0.9745
	25% minimize	0.8524	0.9532
Cropping	Center cropping	0.7318	0.8942
	Side cropping	0.7528	0.8977
Rotation	5 °	0.8596	0.9515
JPEG Compression QF	37.5 %	0.9879	0.9717
	50 %	0.9983	0.9801
	75 %	0.9998	0.9915

TABLE VII: BER AND NCC VALUE COMPARISON WITH SONG *ET AL*. [18] METHOD FOR "LENA" IMAGE

Attacks	[18]		Proposed method	
	BER	NCC	BER	NCC
Sharpening	0.0029	0.9941	0.0098	0.9716
Cropping	0.0811	0.8379	0.0322	0.9123
Luminance	0	NA	0.107	0.9688
Contrast	0	NA	0.0068	0.9802
Noise 3 %	0.0215	NA	0.0117	0.9659
JPEG 90	NA	0.9395	0.0039	0.9887
JPEG 70	0.0752	0.8496	0.0049	0.9858
JPEG 50	NA	0.7988	0.0068	0.9801
Blurring	0.0254	NA	0.0244	0.9326

TABLE VIII: BER VALUE COMPARISON WITH MEHTA *ET AL*. [19] METHOD FOR "PEPPER" IMAGE

Attack	[19]	Proposed Method
No attack	0	0.0049
Salt & Pepper Noise density = 0.5%	0.0557	0.0117
Salt & Pepper Noise density = 1%	0.1230	0.0098
Salt & Pepper Noise density = 2%	0.1973	0.0156
Sharpening	0.0107	0.0107
Histogram Equalization	0.0068	0.0107
Gaussian Noise 0.001	0.0557	0.0146
Gaussian Noise 0.005	0.2637	0.0137
Gaussian Noise 0.01	0.3635	0.0146
Average Filter (3x3)	0.0078	0.0254
Average Filter (5x5)	0.1074	0.0303
Median Filter (3x3)	0.0020	0.0186
Median Filter (5x5)	0.0898	0.0225
Gaussian Filter	0.0020	0.0303
Wiener Filter	0.0010	0.0195
JPEG Compression QF=50	0.0020	0.0059
JPEG Compression QF= 70	0	0.0078
JPEG Compression QF=00	0	0.0049
Scaling 256 to128 to 256	0.0020	0.0146
Scaling 256 to 64 to 256	0.1582	0.0313
Crop top left	0.0605	0.0361
Crop center	0.0518	0.0381
Crop all sides	0.0469	0.0391
Rotation by 0.1	0	0.0146
Rotation by 0.5	0.3291	0.0186
Rotation by 5	0.5023	0.0254
Poisson Noise	NA	0.0166
Speckle Noise	NA	0.0137
Intensity transformation	NA	0.0098
Gamma Correction	NA	0.0137
Shifting	NA	0.0049
Motion blur	NA	0.0371

V. CONCLUSION

This paper presents a novel watermarking scheme using LWT, QR and SVD domain for grayscale images. The performance of proposed technique is represented in terms of imperceptibility and robustness. PSNR and SSIM represent imperceptibility whereas NCC and BER represent robustness. These parameters are computed for six different images. Performance of the proposed methodology is verified without attack and against 21 different attacks. Embedding of watermark at higher level subbands of LWT helps to improve robustness and reduces computational complexity. At individual level QR decomposition and SVD are not resistant to all attacks but combination of QR decomposition and SVD combat the challenge and significantly improves imperceptibility and robustness which is the major contribution of this work.

NCC and BER values indicate significant robustness for almost all attacks barring rotation, cropping and motion blur. A trend observed in most of the existing watermarking technique is, robustness improves with increase in scaling factor but decreases imperceptibility. Proposed technique using combination of QR and SVD in LWT domain is able to combat this issue and maintains both performance parameters for a wide range of scaling factors which is validated by experimental analysis. PSNR and SSIM are nearer to 53 dB and 0.9992 respectively. Similarly, BER is in the range 0.0059 to 0.0078 and NCC is more than 0.9830 for all scaling factors. All four performance parameters PSNR, SSIM, NCC, BER haven't demonstrated distinct variations irrespective of the change in values of scaling factor which is one more contribution of proposed method. The results showed that the proposed algorithm is robust, imperceptible and outperforms existing techniques for attacks. Hence the proposed scheme can be considered as a viable alternative to resolve copyright issues. The current techniques behavior in other subbands can also be explored.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

AUTHOR CONTRIBUTIONS

The contributions given by each of the authors in this research work is as follows: Sushama Agrawal and Anjali Bhalchandra discussed the methods and finalized the technique. Sushma Agrawal carried out implementation of the technique. Both the authors discussed the results and initial manuscript was written by Sushama Agrawal. It was critically revised for important intellectual work together with Anjali Bhalchandra. Sushama Agrawal and Anjali Bhalchandra worked together to put the finishing touches on it.

REFERENCES

[1] F. Ernawan, "Robust image watermarking based on psychovisual threshold," *Journal of ICT Research and Applications*, vol. 10, no. 3, pp. 228–242, 2016.

[2] P. Singh and B. Raman, "A secured robust watermarking scheme based on majority voting concept for rightful ownership assertion," *Multimedia Tools and Applications*, vol. 76, no. 20, pp. 21497–21517, 2017.

[3] H. Tao, L. Chongmin, J. M. Zain, and A. N. Abdalla, "Robust image watermarking theories and techniques: A review," *Journal of Applied Research and Technology*, vol. 12, no. 1, pp. 122–138, 2014.

[4] M. U. Celik, G. Sharma, A. M. Tekalp, and E. Saber, "Lossless generalized-LSB data embedding," *IEEE Transactions on Image Processing*, vol. 14, no. 2, pp. 253–266, 2005.

[5] I.-C. Lin, Y.-B. Lin, and C.-M. Wang, "Hiding data in spatial domain images with distortion tolerance," *Computer Standards & Interfaces*, vol. 31, no. 2, pp. 458–464, 2009.

[6] H. Zhang, C. Wang, and X. Zhou, "A robust image watermarking scheme based on SVD in the spatial domain," *Future Internet*, vol. 9, no. 3, Aug. 2017.

[7] R. Liu, T. Tan, and S. Member, *An SVD-Based Watermarking Scheme for Protecting Rightful Ownership*, 2002.

[8] P. Bao and X. Ma, "Image adaptive watermarking using wavelet domain singular value decomposition," *IEEE Transactions on Circuits and Systems for Video Technology*, vol. 15, no. 1, pp. 96–102, Jan. 2005.

[9] E. Ganic and A. M. Eskicioglu, *Robust DWT-SVD Domain Image Watermarking: Embedding Data in All Frequencies*, 2004.

[10] C. C. Chang, P. Tsai, and C. C. Lin, "SVD-based digital image watermarking scheme," *Pattern Recognition Letters*, vol. 26, no. 10, pp. 1577–1586, Jul. 2005.

[11] A. Mansouri, A. M. Aznaveh, and F. T. Azar, *SVD-Based Digital Image Watermarking Using Complex Wavelet Transform*, 2009.

[12] C. C. Lai and C. C. Tsai, "Digital image watermarking using discrete wavelet transform and singular value decomposition," *IEEE Transactions on Instrumentation and Measurement*, vol. 59, no. 11, pp. 3060–3063, Nov. 2010.

[13] A. K. Gupta and M. S. Raval, "A robust and secure watermarking scheme based on singular values replacement," *Sadhana*, vol. 37, pp. 425-440, 2012.

[14] N. M. Makbol and B. E. Khoo, "A new robust and secure digital image watermarking scheme based on the integer wavelet transform and singular value decomposition," *Digital Signal Processing: A Review Journal*, vol. 33, pp. 134–147, 2014.

[15] M. Awasthi and H. Lodhi, "Robust image watermarking based on discrete wavelet transform, discrete cosine transform & singular value decomposition," *Advances in Electronic and Electric Engineering (AEEE)*, 2013.

[16] J. Y. Wu, W. L. Huang, W. M. Xia-Hou, W. P. Zou, and L. H. Gong, "Imperceptible digital watermarking scheme combining 4-level discrete wavelet transform with singular value decomposition," *Multimedia Tools and Applications*, vol. 79, no. 31–32, pp. 22727–22747, Aug. 2020.

[17] Y. Naderahmadian and S. Hosseini-Khayat, "Fast watermarking based on QR decomposition in wavelet domain," in *Proc. 2010 6th International Conference on Intelligent Information Hiding and Multimedia Signal Processing, IIHMSP 2010*, 2010, pp. 127–130.

[18] W. Song, J.-J. Hou, Z.-H. Li, and H. Liang, "Chaotic system and QR factorization based robust digital image watermarking algorithm," *J. Cent. South Univ. Technol*, vol. 18, 2011.

[19] R. Mehta, N. Rajpal, and V. P. Vishwakarma, "LWT-QR decomposition based robust and efficient image watermarking scheme using Lagrangian SVR," *Multimedia Tools and Applications*, vol. 75, no. 7, pp. 4129–4150, Dec. 2016.

[20] Y. Guo and B. Z. Li, "Blind image watermarking method based on linear canonical wavelet transform and QR decomposition," *IET Image Processing*, vol. 10, no. 10, pp. 773–786, Oct. 2016.

[21] A. M. Abduldaim and M. Q. Hamid, "Robust image watermarking based on QR factorization and LWT," *International Journal of Engineering & Technology*, vol. 7, no. 4, pp. 5358–5362, 2018.

[22] Q. Su, Y. Niu, G. Wang, S. Jia, and J. Yue, "Color image blind watermarking scheme based on QR decomposition," *Signal Processing*, vol. 94, no. 1, pp. 219–235, 2014.

[23] L. Laur, P. Rasti, M. Agoyi, and G. Anbarjafari, "A robust color image watermarking scheme using entropy and QR decomposition," *Radio Engineering*, vol. 24, no. 4, pp. 1025–1032, 2015.

[24] Q. Su, G. Wang, X. Zhang, G. Lv, and B. Chen, "An improved color image watermarking algorithm based on QR decomposition," *Multimedia Tools and Applications*, vol. 76, no. 1, pp. 707–729, Jan. 2017.

[25] S. A. Thajeel, L. M. Kadhim, and S. A. Abdlateef, "A new color image watermarking technique using multiple decompositions," *J. Theor. Appl. Inf. Technol.*, vol. 31, no. 10, 2017.

[26] P. Rasti, S. Samiei, M. Agoyi, S. Escalera, and G. Anbarjafari, "Robust non-blind color video watermarking using QR decomposition and entropy analysis," *Journal of Visual Communication and Image Representation*, vol. 38, pp. 838–847, Jul. 2016.

[27] S. Jia, Q. Zhou, and H. Zhou, "A novel color image watermarking scheme based on DWT and QR decomposition," *Journal of Applied Science and Engineering*, vol. 20, no. 2, pp. 193–200, 2017.

[28] W. Sweldens, "The lifting scheme: A construction of second-generation wavelets," *SIAM Journal on Mathematical Analysis*, vol. 29, no. 2, pp. 511–546, 1998.

[29] V. S. Verma, R. K. Jha, and A. Ojha, "Significant region based robust watermarking scheme in lifting wavelet transform domain," *Expert Systems with Applications*, vol. 42, no. 21, pp. 8184–8197, Jul. 2015.

[30] N. M. Makbol, B. E. Khoo, and T. H. Rassem, "Security analyses of false positive problem for the SVD-based hybrid digital image watermarking techniques in the wavelet transform domain," *Multimedia Tools and Applications*, vol. 77, no. 20, pp. 26845–26879, 2018.

[31] J. M. Guo and H. Prasetyo, "False-positive-free SVD-based image watermarking," *Journal of Visual Communication and Image Representation*, vol. 25, no. 5, pp. 1149–1163, 2014.

[32] S. Bhalerao, I. A. Ansari, and A. Kumar, "Security analysis of SVD-based watermarking schemes and possible solutions," in *Soft Computing: Theories and Applications*, 2021, pp. 529–537.

[33] N. Saikrishna and M. G. Resmipriya, "An invisible logo watermarking using Arnold transform," in *Procedia Computer Science*, 2016, vol. 93, pp. 808–815.

[34] The USC-SIPI Image Database. [Online]. Available: http://sipi.usc.edu/services/database/Database.html

[35] M. Islam, A. Roy, and R. H. Laskar, "SVM-based robust image watermarking technique in LWT domain using different sub-bands," *Neural Computing and Applications*, vol. 32, no. 5, pp. 1379–1403, 2020.

[36] Z. Wang, A. C. Bovik, H. R. Sheikh, and E. P. Simoncelli, "Image quality assessment: From error visibility to structural similarity," *IEEE Transactions on Image Processing*, vol. 13, no. 4, pp. 600–612, 2004.

[37] M. Islam and R. H. Laskar, "Geometric distortion correction based robust watermarking scheme in LWT-SVD domain with digital watermark extraction using SVM," *Multimedia Tools and Applications*, vol. 77, no. 11, pp. 14407–14434, 2018.

Sushama Agrawal was born in 1967 at Mumbai, India. She received the B.E. degree in electronics from Bombay University in 1988 and M.E. degree in electronics from Dr. B.A.M. University, Aurangabad, India in 2001.

She is presently working for Ph.D. degree in electronics engineering at Dr. Babasaheb Ambedkar Marathwada University, Aurangabad. Her areas are image processing, embedded systems and VLSI. She is an associate professor at Government College of Engineering, Aurangabad, Maharashtra, India. She has 28 years of teaching work experience at Diploma, UG and PG levels and has published nearly 20 papers in at National and International level.

Mrs. Agrawal is a life member of Indian Society for Technical Education.

Anjali Bhalchandra was born in 1964 at Nanded, India. She received the B.E. electronics and telecommunication engineering degree from Gulbarga University, Karnataka and M.E. electronics degree from Marathwada University, Aurangabad Maharashtra in 1985 and 1992 respectively. She has completed her Ph.D. in electronics engineering from S.R.T.M. University, Nanded, India, in 2004.

She has scientific and technical background covering the areas of electronics and communication. Currently, she is dean quality assurance and professor of Electronics Department, Government College of Engineering, Aurangabad. Her research interest includes image processing, signal processing and communication. She has 33 years of teaching work experience at UG, PG levels and is Ph.D supervisor since 14 years. She has contributed in 100 plus papers in reputed journals and conference proceedings.

Dr. Bhalchandra is a fellow of the Institution of Engineers, India and life member of Indian Society for Technical Education.