Integer Wavelet Transform and QR Decomposition based Image Watermarking using Lagrangian Twin Support Vector Regression

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Abstract:
In this paper, integer wavelet transform(IWT) and QR decomposition based gray scale image watermarking using Lagrangian twin support vector regression (LTSVR) algorithm is presented. Host image is decomposed using IWT and low frequency subband is divided into non-overlapping blocks. Selected blocks based on the fuzzy entropy are further factorized using QR factorization. Then, significant features of R matrix of each block of the image are used to form the image dataset. This image dataset is supplied to LTSVR algorithm that embeds the scrambled watermark bits in the appropriate coefficient. The proposed method is applied to standard and real world images and its effectiveness is evaluated via the experimental results. From the experimental results, it is inferred that the proposed method outperforms state-of-art approaches in terms of imperceptibility and robustness against various kinds of image processing attacks and thus suitable for copyright protection applications.

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1. Introduction

In the last few decades, the internet has become an excellent distribution system for digital media because it is inexpensive, eliminates warehousing, and delivery is almost instantaneous. Due to these interesting features, people are more interested to download pictures, music and videos. Ownership of multimedia data, illegal copying, avoiding duplicity and copyright protection has become the challenging issue in the age of growing internet and multimedia techniques. Digital watermarking provides a solution to digital contents such as audio, video and image [1-3] for copyright protection, copy protection, proof of ownership (ownership assertion) etc. Digital watermarking for images refers to the process of embedding the secret information called watermark in an imperceptible manner into the original data without losing its visual quality [3-4]. According to domain analysis, digital image watermarking can be classified into spatial and frequency domain watermarking. In the literature of digital watermarking [5-8], it has been found that frequency domain watermarking is more robust as compared to spatial domain watermarking. To enhance the performance of image watermarking methods in terms of imperceptibility and robustness, the use of machine learning algorithms such as artificial neural networks [13, 22], support vector regression [8, 15-16], genetic algorithms [14] and their combination based hybrid image watermarking system are designed by various researchers [17, 22]. Due to the good learning capability of image characteristics and high generalization property of these machine learning algorithms, significant amount of imperceptibility and robustness against image processing attacks is achieved [16-18]. In this paper, a newly designed machine learning algorithm for regression problems called Lagrangian twin support vector regression (*LTSVR*) by Balasundaram *et al*. [10] is employed onto image watermarking applications. The generalization performance of *LTSVR* on synthetic datasets which is obtained from UCI repository and against noisy datasets is already examined [8-9]. Assuming the watermarking problem as a regression problem, our aim in this manuscript is to propose a new robust image watermarking approach against image processing operations and used for copyright protection applications.

- Transform the original image from spatial domain to frequency domain using IWT [23-24] and select the low frequency wavelet coefficient which has high energy compaction property.
- Selection of low frequency blocks based on the fuzzy entropy of each block and each selected block is factorized using QR [19-20] decomposition to select significant coefficient for embedding the watermark from each block and form the image dataset. Fuzzy entropy [12] is sensitive to image variations; it is used for selecting smooth non overlapping blocks and discards blocks with redundant data.
- To enhance the robustness, LTSVR [10] is used to learn the image features and after training, trained LTSVR is used to embed the watermark in testing blocks with optimal value of watermark strength which is obtained by performing a number of experiments on all test images.
- In addition to imperceptibility and robustness, the security of the watermark is obtained by applying Arnold transformation [11] to get the scrambled watermark bits which is embedded into the host signal.

The rest of the paper is arranged in the following manner.In the next section, the work related to proposed approach such as formulation of LTSVR, QR decomposition, IWT and fuzzy entropy is described in Section 2.The proposed image watermarking scheme is discussed in Section 3. Experimental results along with the comparative analysis of the proposed scheme are explained in Section 4. Finally the conclusionis drawn in Section 5.

2. Preliminaries

2.1 Entropy and Fuzzy Entropy

Entropy is a measure of randomness in a signal or how much information is kept in a signal. Image randomness can be measured using histogram analysis, Shannon entropy measure and adjacent pixel correlation. In recent years, fuzzy entropy [12, 25] becomes the powerful tool for image analysis; it is used to measure image randomness. In this work, it is observed that fuzzy entropy [12] is sensitive to image variations; it is used for selecting smooth non overlapping blocks and discards blocks with redundant data.In the following fuzzy entropy is described as:

For any fuzzy set *F* defined on a universal set *U*, its cardinality denoted by F , is defined by the formula

$$|F| = \sum_{x \in U} \mu_F(x) \tag{13}$$

where $\mu_F(x)$ is the membership value of element of fuzzy set *F.* Fuzzy entropy is computed by the intersection and union operation of fuzzy sets [26]. The degree of randomness of a fuzzy set is defined by the fuzzy entropy as:

$$FE(F) = \frac{(F \cap F^{'})}{(F \cup F^{'})} \tag{14}$$

Where union and intersection for two fuzzy sets *F* and *G* isdefined by the formulas [26]:

$$F \cup G = \max\{\mu_F(x), \mu_G(x)\}, \quad F \cap G = \min\{\mu_F(x), \mu_G(x)\} \tag{15}$$

and complement of a fuzzy set is given by:

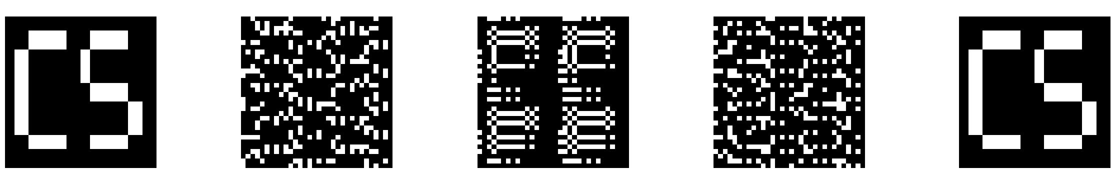
$$F^{'} = \{1 - \mu_F(x)\} \tag{16}$$

3. Proposed Algorithm for Watermarking

We experimented on eight-bit grayscale image *I*of dimensions$512 \times 512$is given by $I = \{I(i,j): 1 \leq i \leq P, 1 \leq j \leq Q\}$. The size ofthe binary watermark is $N1 \times N2$. The proposed scheme for watermark embedding and extracting is explained if following sections.

3.1 Watermark Embedding

1. Scrambled the original watermark using Arnold transformation [11] for the security of watermark. Different versions of scrambled watermark along with original watermark are shown in Fig. 2(a) to Fig. 2(d). In our experimental work, we have used scrambled image after *12th* pass to embed into the host image.



(a) Original Watermark (b) 6th Pass (c) 12th Pass (d) 18th Pass (e) 24th Pass

Fig. 2 Scrambled Images of watermark after applying Arnold Transformation

2. Host image is decomposed using IWT and low frequency sub band denoted by *LL* is splitted into mutually exclusive blocks,each of size 4×4. Randomness measurement of eachblock is found by fuzzy entropy using Eq. 16 and the blocks are arranged in non-

increasing order. Select first $m \ (m = 2 \times size\_of\_watermark)$ no. of blocks for extracting the robust feature for inserting the scrambled watermark image.

3. Every selected block of Step 2 isfactorizedby QR method (Eq. 9) to obtain $R$and$Q$ as upper triangular and unitary matrix respectively each of size 4×4. The feature of matrix R as shown in Fig. 3 is that the total value of each entry of first row is greater as compared to the entries of other rows. From the investigational results performed on all test images, it is found that the appropriate element for inserting the watermark in all the blocks is $r_{1,3}$ which shows maximum robustness. So, $r_{1,3}$ of all the blocks areset as target to LTSVR and rest of the upper triangular entries represented by $\{r_{1,1}, r_{1,2}, r_{1,4}, r_{2,2}, r_{2,3}, r_{2,4}, r_{3,3}, r_{3,4}, r_{4,4}\}$are set as feature vector for the learning of LTSVR. Hence an image datasetis formed by combining the features and target of every block of size $m \times n$.

$$\begin{bmatrix} r_{1,1} & r_{1,2} & r_{1,3} & r_{1,4} \\ 0 & r_{2,2} & r_{2,3} & r_{2,4} \\ 0 & 0 & r_{3,3} & r_{3,4} \\ 0 & 0 & 0 & r_{4,4} \end{bmatrix}$$

Fig. 3 R matrix used for constructing image dataset

4. After collection of important features from R matrix, an image dataset DS is created to instruct LTSVR:

$$DS = \begin{Bmatrix} (x_i, d_i) \in R^9 \times R : i = 1,2,...,m \\ = \{(r_{1,1}, r_{1,2}, r_{1,4}, r_{2,2}, r_{2,3}, r_{2,4}, r_{3,3}, r_{3,4}, r_{4,4}), r_{1,3}\} \end{Bmatrix}$$

Where $r_{1,3}$ is the target output and its nine upper triangular elements as shown in Fig. 3 act as input to LTSVR. In all the experiments, half samples are used for the traing purpose of

LTSVR defined by Eq. 8 i.e. $DS = \{(x_i, d_i) : i = 1,3,5,\ldots,m\}$.Then, trained LTSVR is used for predicting the output using Eq. (4) of remaining even samples in which the watermark is embedded on comparing with the LTSVR output and target values. Then, scrambledbinary sequence of watermark are embedded by applying the below rule:

$$\begin{aligned} & if\ wm\_bit = 1 \\ & \qquad r_{1,3}^{'} = \max(r_{1,3}, r_{1,3}^{LTsvr} + \alpha) \\ & else \\ & \qquad r_{1,3}^{'} = \min(r_{1,3}, r_{1,3}^{LTsvr} - \alpha) \end{aligned} \quad (17)$$

where, $r_{1,3}^{'}$ is the modified value after embedding the watermark and is replaced with original $r_{1,3}$ element of R matrix of each selected block, $r_{1,3}^{LTsvr}$ is the predicted output obtained by trained LTSVR, α is the watermark strength and wm_bit is the scrambled watermark bit. The value of α is chosen after a performing a number of repetitions experiments and it is found that imperceptibility and robustness tradeoff can be minimized for $\alpha = 5$.

5. After replacing $r_{1,3}$ with $r_{1,3}^{'}$ of every selected block of R matrix, the inverse of QR andIWT decomposition is applied for the formation of watermarked image. Peak signal-to-noise-ratio (PSNR) is used to assess the watermark imperceptibility and quality of watermarked image.

6. Watermark Extracting

Having the indexes of the non overlapping blocks along with the signed image, the watermark is extracted using the following steps:

1. One level IWT decomposition is applied to the watermarked image and the low frequency sub band is divided into non overlapping blocks and according to the index used in embedding process, blocks of $LL^{'}$ sub band are selected.

2. Each selected block factorized using QR decomposition given by Eq. 9 to obtain upper

triangular matrix $R^{'}$ shown in Fig. 3, each of size 4×4. Similar to Step 4 of embedding process, dataset is formed.To perform watermark extraction,even number of data samples

$$DS = \left\{ \begin{array}{l} (x_i, d_i) \in R^9 \times R : i = 2,4,...,m \\ = \left\{ \left(r^{'}_{1,1}, r^{'}_{1,2}, r^{'}_{1,4}, r^{'}_{2,2}, r^{'}_{2,3}, r^{'}_{2,4}, r^{'}_{3,3}, r^{'}_{3,4}, r^{'}_{4,4} \right), r^{'}_{1,3} \right\} \end{array} \right\}$$

are supplied to trained LTSVR to get the output $r_{1,3}^{LTsvr} : i = 2,4,6,...,m$ corresponding to desired output $d_i = \left\{ r^{'}_{1,3} : i = 2,4,6,...,m \right\}$. Then, compare the LTSVR predicted value with the desired output $D_i = \left\{ r^{'}_{1,3} : i = 2,4,6,...,m \right\}$ corresponding to each block of the watermarked image to extract the scrambled binary sequence $SW^{'}_m$

$$SW^{'}_m = \begin{cases} 1 & if \quad r^{'}_{1,3} > r_{1,3}^{LTsvr} \\ 0 & otherwise \end{cases} \quad (18)$$

where, $r_{1,3}^{LTsvr}$ is the LTSVR output and $r^{'}_{1,3}$ is the desired output value of each block.

3. Arnold transformation is applied to the scrambled watermark obtained in Step 2 so that originality of the recovered watermark is verified. Two metrics bit correct ratio (BCR) and normalized correlation (NC) is computed for the verification of extraction procedure.

4. Assessment of Proposed Approach

Six standard gray scale images which includes smooth and textured ones such as *Lena, Pepper, Boat, Baboon, Cameraman, Plane* and two real world images *Home and Childlake* with size 512×512 shown in Fig. 4 are used for experiment purpose to test the imperceptibility and robustness. All the experimental results are performed in MATLAB 7.10 platform. Two different binary watermarks *CS* and *IPU*of size 32×32 shown in Fig. 5 are used in this work for the validity of the proposed method. The optimal value of *LTSVR* parameters $C1 = 50$ & $C2 = 100$ and the spread of RBF kernel $\sigma = 10^{-3}$ are determined by 10-fold cross validation on the training dataset by varying $C1 = C2 = \{50,100,...,500\}$ and $\sigma = \{10^{-3},10^{-2},..,10^{3}\}$ respectively. The learning capability of *LTSVR* and its generalization performance against noisy datasets is tested by performing number of image processing attacks on all test images and corresponding results are given in Table 1 and Table 2. *LTSVR* requires more parameters to be selected as compared to *LSVR*[10] which leads to slow the learning speed.

Imperceptibility and Robustness investigation

The imperceptibility of the watermark and quality of the watermarked image is estimated by PSNR using Eq. (19):

$$PSNR = 10\log_{10}\frac{255^2}{MSE}\ (dB) \quad (19)$$

The mean square error (*MSE)* between the host and watermarked image is computed by Eq. (20):

$$MSE = \frac{\sum_{x=1}^{M}\sum_{y=1}^{N}\left(I(x,y) - I^{'}(x,y)\right)}{M \times N} \quad (20)$$

where $I(x,y)$ and $I^{'}(x,y)$ denote the value of y^{th} pixel of the x^{th} row of the host image I and the watermarked image I' respectively with size $M \times N$. BCR and NC values areestimated to verify the quality of extracted watermark W^* with the original watermark W using Eq. (21) and Eq. (22):

$$BCR\left(W,W^*\right) = 1 - \frac{\sum_{i=1}^{N1}\sum_{j=1}^{N2} W(i,j) \otimes W^*(i,j)}{N1 \times N2} \quad (21)$$

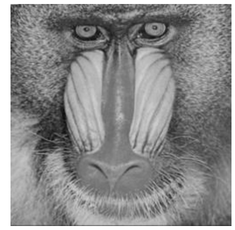
$$NC(W,W^*) = \frac{\sum_{i=1}^{N1}\sum_{j=1}^{N2} W(i,j) * W^*(i,j)}{\sum_{i=1}^{N1}\sum_{j=1}^{N2}\left[W(i,j)\right]^2} \quad (22)$$

Fig. 6 shows the watermarked images along with the extracted watermark corresponding to Fig. 4 and Fig. 5(a) respectively.


a. Lena


b. Pepper


c. Boat


d. Baboon

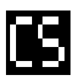

e. Cameraman


f. Plane


g. Home


h. Childlake

Fig. 4 Original gray scale images of size 512 x 512

a. 

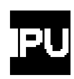
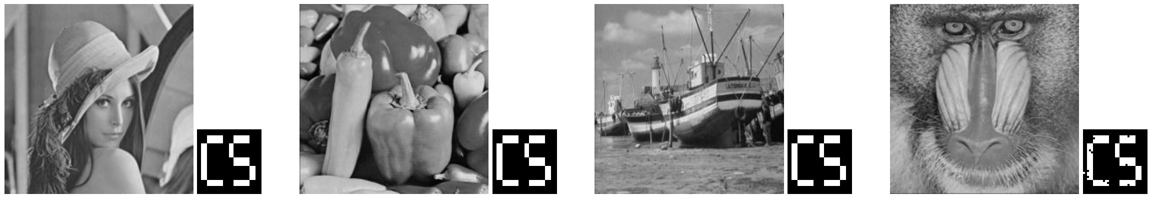
b. 

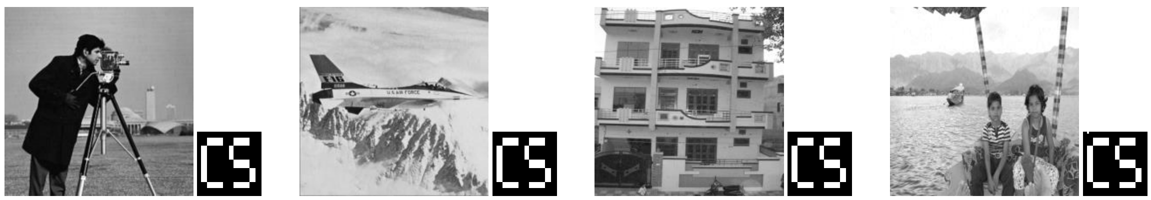
Fig. 5 Original Watermarks

The high PSNR values of watermarked images demonstrate the good imperceptibility of the watermark and BCR value equal to one of the extracted watermark against without attacks case proves the imperceptibility of the proposed approach. The parameters used for the perceptual quality of watermarked imagesand recovered watermark indicated by PSNR and BCR respectively are shown in Fig. 6. To test the robustness of the proposed approach, different image processing attacks listed in first column of Table 1 are performed on all the watermarked imagesand then watermark removal process is performed and the results obtained on all test images are listed in Table 1 and Table 2.



a. Lena   b. Pepper   c. Boat   d. Baboon

PSNR:49.3409, BCR: 1   PSNR:44.9996, BCR: 1   PSNR:45.3641, BCR: 1   PSNR:42.7153 , BCR: 1



e. Cameraman   f. Plane   g. Home   h. Childlake

PSNR:48.9887, BCR: 1   PSNR:49.6915, BCR: 1   PSNR:44.8450, BCR: 1   PSNR:45.7773, BCR: 1

Fig. 6Watermarked images along with extracted watermark correposding to Fig. 4 and Fig. 5 (a).

The visual depiction of extracted watermark from the distorted versions of *Cameraman* and *Home*that is attacked under filtration, JPEG compression, contrast enhancement, sharpening and addition of Gaussian, salt and pepper noise is shown in Fig. 7 and Fig. 8 respectively. The results listed in Table 1 and Table 2, it is inferred that the watermarking approach described in this paper could be applied for copyright protection applications. This is due to the selection of low frequency subband obtained using IWT and the significant element of matrix R to insert the watermark. The good learning and generalization of LTSVR accompanied with IWT and QR is accountable for giving good imperceptibility and high robustness against attacks in the proposed work.

Table 1 BCR, NC value for attacked images *Lena*, *Pepper*, *Boat* and *Baboon*

Attacks / Images	***Lena* (45.6552 dB)**		***Pepper* (44.9996 dB)**		***Boat* (45.3641 dB)**		***Baboon* (42.7153dB)**	
	BCR	NC	BCR	NC	BCR	NC	BCR	NC
No Attack	1	1	1	1	1	1	0.9893	0.9761
Median Filter	0.9912	0.9812	0.9551	0.9101	0.9395	0.8585	0.873	0.7271
Average filter	0.9561	0.9079	0.9248	0.857	0.9209	0.8132	0.7979	0.5605
JPEG compression	1	1	0.9922	0.9833	0.9971	0.9936	0.9512	0.8914

(QF=50)								
Sharpening	0.9717	0.9388	0.9883	0.9741	0.9668	0.9332	0.96	0.9193
Histogram Equalization	0.9893	0.977	0.9932	0.9853	0.9639	0.9235	0.8701	0.7954
Gaussian noise (5%)	1	1	1	1	0.9951	0.9892	0.9814	0.9587
Gaussian noise (10%)	0.9639	0.9249	0.959	0.9176	0.9697	0.9326	0.9404	0.873
Salt &Pepper noise (1%)	0.9438	0.9232	0.8867	0.7985	0.9063	0.8158	0.9053	0.8103
Salt &Pepper noise (2%)	0.9122	0.8586	0.8281	0.7089	0.8418	0.7308	0.833	0.701

Table 2 BCR, NC value for attacked images*Cameraman*, *Plane*, *Home* and *Childlake* images

Attacks / Images	***Cameraman* (46.1477 dB)**		***Plane* (45.5188 dB)**		***Home* (44.8450 dB)**		***Childlake* (45.7773 dB)**	
	BCR	NC	BCR	NC	BCR	NC	BCR	NC
No Attack	1	1	1	1	1	1	0.999	0.9979
Median Filter	0.9971	0.9936	0.999	0.9979	0.9434	0.8814	0.9717	0.9385
Average filter	0.915	0.7974	0.9736	0.9462	0.9131	0.8171	0.9199	0.8287
JPEG compression (QF=50)	1	1	0.999	0.9979	0.9893	0.9766	0.9941	0.9871
Sharpening	0.9873	0.9726	0.9951	0.9892	0.9697	0.9368	0.9854	0.9682
Histogram Equalization	0.999	0.9979	0.998	0.9957	0.9688	0.9354	0.9795	0.9571
Gaussian noise (5%)	1	1	1	1	0.9961	0.9914	0.998	0.9957
Gaussian noise	0.9727	0.9387	0.9736	0.9447	0.9697	0.9333	0.958	0.912

(10%)								
Salt &Pepper noise (1%)	0.9023	0.8142	0.9395	0.8817	0.8906	0.7945	0.916	0.8281
Salt &Pepper noise (2%)	0.8311	0.7164	0.8496	0.7299	0.8398	0.7301	0.8184	0.6744

Fig. 7 Extracted watermark against image processing attacks on watermarked *Cameraman* image (a) Median filtering (b) Average filtering (c) JPEG Compression having QF=50 (d) Sharpening (e) Contrast enhancement (f) 5% Gaussian noise addition (g) 10% Gaussian noise addition (h) Salt and Pepper noise addition of 1% (i) Salt and Pepper noise addition 2%

Fig. 8Extracted watermark against image processing attacks on watermarked *Home* image (a) Median filtering (b) Average filtering (c) JPEG Compression having QF=50 (d) Sharpening (e) Contrast enhancement (f) 5% Gaussian noise addition (g) 10% Gaussian noise addition (h) Salt and Pepper noise addition of 1% (i) Salt and Pepper noise addition 2%

Comparative Analysis

The performance of the proposed method is evaluated by comparing robustness against image processing attacks such as median filtering, average filtering, JPEG compression, sharpening, contrast enhancement, addition of Gaussian noise, addition of salt and pepper noise etc. with the schemes described by Meng *et al*. [8], Peng *et al.*[15] and Agarwal's *et. al.* [22]. For fair comparison similar kind of images are used in our experiments as in [8, 15, 22]. Firstly, the comparison with Meng *et al*. method [8] based on the BCR value of extracted watermark against image processing attacks is verified as listed in Table 3. In addition to BCR value, the visual representation of extracted watermark is shown in col. 4 of Table 3. From Table 3, high BCR value of extracted watermark by the proposed method as compared with [8] showed more robust against image processing attacks.

Table 3 Comparison of BCR value of extracted watermark of the proposed scheme with Meng *et al.* method [8] on *Lena* image under different image processing attacks.

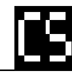
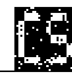
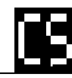
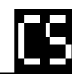
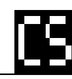
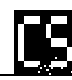
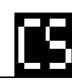
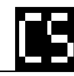
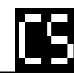
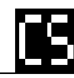
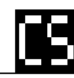
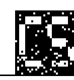
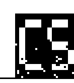
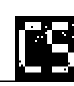
Attacks / Image	Lena		Extracted watermark using proposed scheme
	Meng's method	Proposed Scheme	
Attack Free	1	**1**	
Low-pass Filtering (LPF)	0.9517	**0.9562**	
Median Filtering (MF)	0.8608	**0.9912**	
JPEG (60)	0.954	**1**	
JPEG (90)	1	**1**	
Scaling (50%)	0.9351	**0.9562**	
Scaling (75%)	0.9658	**0.9845**	
LACE	0.5017	**0.9893**	
Salt and Pepper Noise (0.02)	0.7205	**0.9122**	

Table 4 shows the robustness comparison between proposed method and scheme proposed by Peng et. al.[15] for the *Boat* image. From Table 4, the watermark extracted by proposed scheme has better visual perception in almost all the cases than those extracted by [15] as measured by the bit error rate (BER) computed using BER = 1-BCR value. Thus the results obtained on standard and real world images prove the effectiveness of the proposed scheme in terms of imperceptibility and robustness. Besides imperceptibility and robustness, the security of the watermark is also achieved by the Arnold transformation. Based on the imperceptibility, robustness and security obtained using proposed method, it is inferred that proposed scheme is useful for copyright protection where high degree of robustness is required and could be applied to real world applications.

Table 4 Comparison of BER (W, W*) value of extracted watermark of the proposed scheme with Peng et al. [15] method on *Boat* image under different image processing attacks.

Attacks / Image	Boat		Extracted watermark using proposed scheme
	Peng's method	Proposed Scheme	
Attack Free	0	**0**	
JPEG (QF=80)	0.0946	**0**	
JPEG (QF=50)	0.2215	**0**	
Low pass filtering	0	**0**	
Median filtering	0.3013	**0.0601**	
Average filtering	0.2023	**0.0815**	
Salt & pepper noise (2%)	0.1017	0.1982	
Gaussian noise	0.1246	**0.0987**	
Scaling (50%)	0.1835	**0.0258**	
Rotation (15deg.)	0.1025	**0.5536**	
Blurring	0.0536	**0.0215**	
Sharpening	0.0143	0.0472	

Thirdly, the comparison of the proposed LTSVR based scheme is evaluated with the scheme defined by Agarwal's *et. al.* using the combination of neural network and genetic algorithm [22] is described in Table 5. The various types of image processing operations such as Gaussian blur, addition of Gaussian noise, median filtering, scaling, contrast enhancement, jpeg compression, cropping and rotation are performed on standard as well as real world images and it is evident from Table 5 that the high NC value of the extracted watermark using the proposed method gives better visual quality of extracted watermark.

Table 5NC value comparison of extracted watermark against different attacks with method [22]

Attacks/images	Pepper		Lena		Boat		Baboon	
	Agarwal's method [22]	Proposed method	Agarwal's method [22]	Proposed method	Agarwal's method [22]	Proposed method	Agarwal's method [22]	Proposed method
Attack free	1	**1**	1	**1**	1	1	1	0.9867
Gaussian blur	0.9512	**1**	0.9442	**1**	0.961	**1**	0.9323	**0.9647**
Gaussian noise (10%)	0.9121	**0.9176**	0.9056	**0.9249**	0.856	**0.9697**	0.9023	**0.9404**
Median filter	0.9214	0.9101	0.9013	**0.9812**	0.9453	**0.9585**	0.9006	0.8914
Brightness & contrast	1	0.9932	1	**0.9893**	0.9967	0.9939	1	0.8901
Scaling (512-256-512)	0.9914	**1**	1	**1**	1	1	1	1
JPEG (QF=50)	0.9957	0.9833	1	**1**	0.9914	**0.9936**	1	0.9512
Crop(25% and fill the missing portion with host image)	0.7557	**0.9465**	0.7554	**0.9752**	0.7453	**0.9647**	0.7554	**0.8647**
Rotation (180)	0.9415	0.6735	0.934	0.5467	0.9653	0.5246	0.9459	0.6138

This is due to the (1) extracting the low frequency features using integer wavelet transform (2) selecting the appropriate coefficient for embedding the watermark using QR decomposition and (3) good generalization ability of LTSVR against noisy datasets (image processing attacks) as compared to back propagation neural network makes the proposed method more imperceptible and robust. The authors of [22] showed the results only on standard images not onto the real world images, whereas the proposed method is useful to real world copyright protection applications.

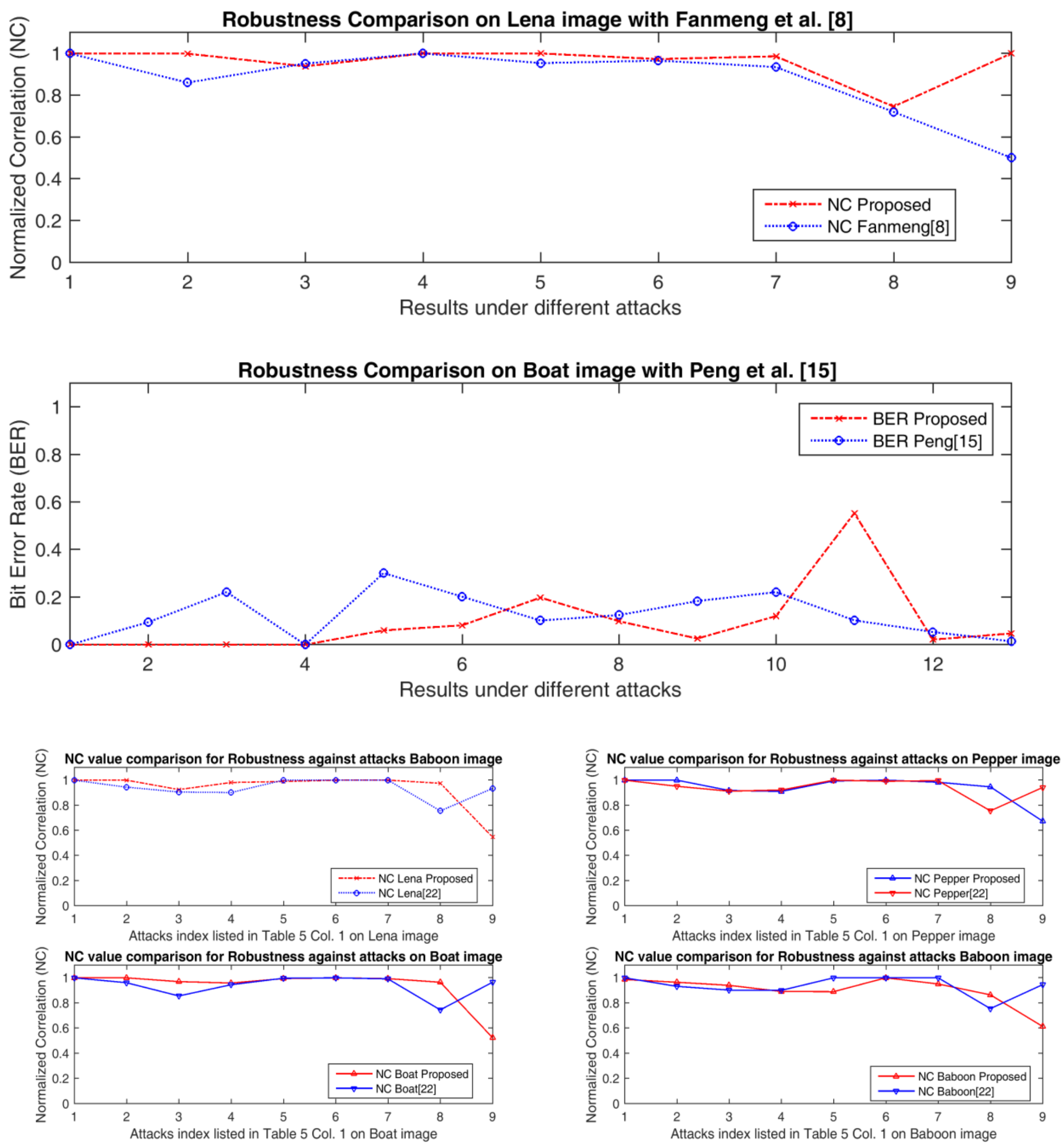


Fig. 9Robustness comparison of the proposed method with [8, 15, 22]

The performance of the LTSVR onto classification and regression problems on synthetic and real world datasets have been verified Balasundaram *et. al.* [10] and it has been shown that LTSVR performance is better or similar to Lagrangian support vector regression (LSVR). In this research work, the main focus is to test the performance of LTSVR onto image watermarking applications whereas LSVR is already applied onto image watermarking in our earlier work [18]. With the results obtained on standard and real world image datasets, it is inferred that the proposed watermarking scheme is highly imperceptible and robust with respect to recently developed schemes. The comparison result of the proposed scheme is illustrated in Fig. 9.

Conclusions: A novel gray scale image watermarking scheme based on LTSVR is explored by combining the advantage of IWT and QR decomposition.Robust feature are extracted using IWT and prominent coefficient of selected blocks (based on fuzzy entropy) of low frequency sub-band using QR factorization method is used to embed the scrambled watermark. The robustness against several image processing operations is accomplished by the good learning of image characteristics and high generalization property of LTSVR against noisy datasets. The security of the watermark is achieved using Arnold transformation. Faster and efficient implementation of IWT, QR and LTSVR as compared to DWT, SVD and classical SVR respectively makes the proposed scheme more efficient in terms of memory requirement and computational cost in addition to imperceptibility and robustness.

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