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Lifting Wavelet Transform with Singular Value Decomposition for Robust Digital Image Watermarking

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ABSTRACT
Digital image watermarking is proposed using lifting wavelet transform and singular value decomposition for copyright protection and authentication. In this paper, lifting wavelet transform (LWT) transforms the image into subbands. The subband having energy greater than computed 'Q' value is selected for watermark embedding. Singular value decomposition (SVD) matrix is derived for this subband and used to embed the gray level digital signature as a watermark. This watermarking is useful for real time application since split and merge process in LWT reduces computational complexity by 50%. Loss in information is less as compared to discrete wavelet transform (DWT) algorithm, because in LWT based algorithm down and up sampling is not using. Also, use of SVD lends noninvertible property to the watermarking so that fake watermarked image cannot be generated. This algorithm is spread spectrum thus robust and semi blind needs singular values of original image for retrieval of watermark.
The proposed algorithm is tested for robustness against eighteen attacks on each of the five different images. Experimental results and analysis show that proposed algorithm is trustworthy in establishing the ownership and, is robust against different attacks. Correlation coefficient (CRC) values obtained from proposed LWT-SVD algorithm are compared with DWT-SVD method.

Keywords
Digital Image Watermarking, Lifting Wavelet Transform, Singular Value Decomposition

1. INTRODUCTION
1.1 Motivation
Use of multimedia technology and computer networking is all over the world. Therefore, problem of illegal reproduction, modifications and the illegal claim of ownership has become more serious than before. Therefore, to provide security to the digital multimedia is an important issue. To tackle this problem, watermarking technique embeds owner's identity information into digital information such as text, image, video and audio and provides the proof for corresponding authentication system. Invisibility of watermark, robustness of watermark against any type of attacks and noninvertible property of watermark are the requirements of any watermarking scheme [1]. Robustness of the watermarking scheme is based on watermark embedding technique, capacity of watermark, strength of watermark, spreads of watermark over the image and intactness of watermark after attacks. If it is not possible to generate fake watermark is the noninvertible property and should provide reliable protection to the rightful ownership. To fulfill above requirements LWT and SVD plays a very important role.
The main motivation of this work is to provide a robust digital signature watermarking, using joint approach comprising of LWT-SVD to protect images against attacks and authenticate ownership of image without degrading the quality of image. This algorithm is spread spectrum, semi blind, and non-invertible. It also achieves higher robustness and improved fidelity, which is one of the important challenges of the watermarking. Proposed method is semi blind because the singular values of original image is required to retrieve the watermark.

1.2 Previous Work
SVD based watermarking is present in past literature. Quan and Qingsong [2] embedded the singular values of the watermark to the singular values of the mid band DCT coefficients. Tong et al. [3] proposed a blind digital image watermarking scheme based on SVD and fast Independent Component Analysis (ICA) algorithm. Aslantas [4] presented algorithm using SVD with genetic algorithm to get transparent and robust watermarking. Qi et al. [5] presented a blind adaptive quantization index modulation and SVD based watermarking scheme to embed watermark bits in the approximate subband of wavelet domain. This method is robust against JPEG compression attack. A semi-blind reference watermarking scheme based on DWT-SVD for copyright protection and authenticity is presented by Bhatnagar and Raman [6]. Al-Haj and Manasrah [7] generated an imperceptible and robust digital image watermarking algorithm based on cascaded DWT and SVD. Senthil and Bhaskaran [8] proposed a work, which is based on wavelet transformation methods that embeds and extracts the watermark in digital images with the considerations of perceptual transparency and robustness against geometric attacks. Most of the previously suggested schemes are based on DWT, SVD independently or DWT-SVD in combination. Author's also developed a bit plane method to improve robustness [9] and wavelet with subband threshold computing method [10] to improve fidelity of watermarked image.

1.3 Main Contribution
The main contributions of this paper are summarized as follows. Firstly, a novel method based on combined use of LWT and SVD is proposed, for digital image watermarking, which can be useful for real time applications. This is most suitable to keep watermark intact to the original image and retrieve it efficiently. The correlation coefficient between original watermark and retrieved watermark is observed to be high even after different intentional and non-intentional

attacks indicating retrieval of watermark is lossless and very efficient with proposed method. Therefore this is more reliable method to prove ownership and authentication of digital information.

Secondly, it is also observed that as compared to the DWT-SVD, combination of SVD with LWT increases PSNR (peak signal to noise ratio) which indicates increased fidelity. Finally, the watermarking with proposed algorithm is tested against eighteen different attacks (intentional and unintentional) and found to be robust. Also, proposed method is compared with Bhatnagar and Raman [6] method for validation.

Rest of the paper is organized as follows: In section 2, fundamentals of LWT and SVD are discussed. Proposed watermark embedding and retrieval process is discussed in section 3. The results of the proposed algorithm and comparison with earlier method are discussed in section 4, and it is followed by conclusion.

2. LWT AND SVD

2.1 Lifting Wavelet Transform

LWT with standard 4-tap orthonormal filter with two vanishing moments is used for digital image watermarking. LWT is an alternative approach for DWT to transform image into frequency domain [11] for real time applications. Lifting wavelet is the second generation fast wavelet transform. In this, translation and dilation are not fundamental to obtain lifting wavelets. In lifting wavelet transformation, up and down sampling is replaced simply by split and merge in each of the level. The polyphase components of the signal are filtered in parallel by the corresponding wavelet filter coefficients, producing the better result than up and down-sampling which is required in traditional DWT approach [12].

In comparison with general wavelets, reconstruction of image by lifting wavelet is good because, it increases smoothness and reduces aliasing effects [13]. Employing LWT reduces loss in information, increases intactness of embedded watermark in the image and helps to increase the robustness of watermark.

reconstruction is crucial to achieve good fidelity in digital image watermarking. In addition to this, it reduces the computational complexity almost to a half as compared to convolution approach in DWT [16]. In this decomposition, filter coefficients are converted into lifting coefficients (predict s(z), update t(z) and scaling (k)) using Euclidian algorithm and original image is split into (odd and even) sets of samples. Further lifting coefficients are applied on the sampled original image to get approximate and detail subbands.

2.2 Singular Value Decomposition

If watermark is embedded into a singular value of selected subband imperceptibility, robustness and perfect reconstruction is achieved. SVD is a linear algebraic numerical technique and used to form diagonalizable matrices in numerical analysis. Singular value matrix forms the characteristic equation, and the degree of characteristic equation is equal to the dimension of column or row of the image. If the watermark is embedded into singular values of an image, it has very good stability and does not have degradation because singular values represent algebraic image properties which are intrinsic and not visual [1].

A new way to enhance the characteristics i. e. robustness and fidelity in the digital image watermarking is achieved by using unique characteristics of LWT-SVD. The flow chart for decomposition of image into frequency domain using LWT is as shown in Fig. 1. Reconstruction is exact opposite to the decomposition.

3.PROPOSED LWT-SVD BASED ALGORITHM

In proposed algorithm, first step is to decompose the image into subbands using LWT. In second step, intensities of subbands are compared to the computed 'Q' value. The subband which is having intensity more than Q value is used further for singular value decomposition and watermark is embedded in it. Finally, the watermarked image is reconstructed by inverse LWT. The algorithm also provides watermark retrieval process which is described at the end of this section. The details of this algorithm are as follows:

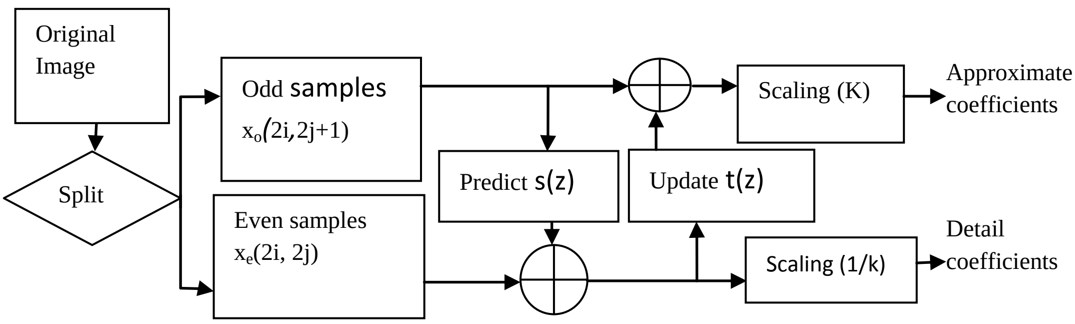


Fig.1 Original image is transform into frequency domain (subbands) using LWT

Lifting wavelet is non linear wavelet transform, which does not use down and up sampling. It is also having better computational efficiency. LWT is also helpful to avoid the existence of boundary artifacts that are generally present in general wavelet [14]. Lifting transform also provides several advantages [15] like less memory requirements, reduced distortion and aliasing effects, good reconstruction, less computation and computational complexities.

Employing SVD in combination with LWT leads to ease in watermark retrieval, improves the intactness of watermark, spreads the watermark through out the spectrum, and imparts non-invertible property to the watermarking. This effective

3.1.Decomposition of Image using LWT

In proposed algorithm, three steps are involved in the space-frequency domain transformation viz; split, lifting, and scaling (normalization). Further, lifting process consists of two steps viz; primal (predict) lifting and dual (update) lifting. The image is decomposed first horizontally and then vertically to get subbands. Horizontal decomposition of an image is carried out in three steps split, lifting and normalization as follows:

i. Split: Splitting of an image into even and odd pixel coefficients called array of polyphase matrix. The rows of the array are processed first with only one level of decomposition. This essentially divides the array into two vertical halves.

Consider original image $X = (x_k)_{k \in Z}$ with $x_k \in R$. This original image is split in two disjoint sets using lazy wavelet transform as shown in fig.2. These are called the polyphase components. The first one is called even indexed samples $x_e(2i, 2j)$, or "evens" short, and second the odd indexed samples $x_o(2i,2j+1)$, or "odds" forming two vertical halves (L-band and H-band respectively). Typically these two sets are closely correlated. Where, $m=2i$ and $n=2j$ for even samples.

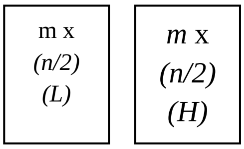


Fig.2.Vertical halves

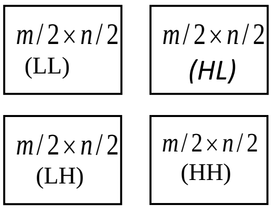


Fig.3. Horizontal halves for (L and H halves)

ii. Lifting process: After splitting the image into two halves consisting of separately even and odd pixel coefficients, the lifting process is carried out as follows.

- ***Primal lifting (predict):*** Primal lifting is also called as prediction. Even pixel coefficients are predicted using primal lifting coefficients $\tilde{s}(z)$. These coefficients are added into the odd pixel coefficients of the image as the first step to get detail coefficients in frequency domain. Detail coefficients of level one are obtained in (1).

$$H_{d\ (i,j)}^{(1)} = x_o(2i,2j+1) - \sqrt{3}x_e(2i,2i) \qquad (1)$$

- ***Dual lifting (update):*** Dual lifting is also called as updating. Detail coefficients obtained, as above, are updated using lifting coefficients $\tilde{t}(z)$ and added into even pixel coefficients of image to get approximate coefficients of image into frequency domain. Approximate coefficients of level one are obtained as follows:

$$L_{s\ (i,j)}^{(1)} = x_e(2i,2i) + \sqrt{3}/4H^{(1)}(i,j) + (\sqrt{3}-2)/4H^{(1)}(i,j+1)$$
(2)

- ***Primal lifting:*** Level two detail coefficients (3) are obtained from details and approximates of level one. Here the approximate of level one is predicted and added to details of level one.

$$H_{d(i,j)}^{(2)} = H_d^{(1)}(i,j) + L_s^{(1)}(i,j-1) \qquad (3)$$

iii. Normalization: To normalize the frequency domain coefficients, scaling factor is applied. This is obtained in (4) and (5).

$$L_{s(i,j)} = (\sqrt{3}+1)/\sqrt{2}L_s^{(1)}(i,j) \qquad (4)$$

$$H_{d(i,j)} = (\sqrt{3}-1)/\sqrt{2}H_d^{(2)}(i,j) \qquad (5)$$

These vertical halves of an image, dimension is further split *m* x*(n/2)* into even and odd pixel (*m/2*)x*(n/2)*coefficients of size by applying the same steps as above, to get subbands shown in fig.3.

3.1.1 Selection of Subband for Watermarking

Selection of the subband for watermark embedding is as follows:

$$Sum = \left(\sum_{i=1}^{m}\sum_{j=1}^{n} LL(i,j) + \sum_{i=1}^{m}\sum_{j=1}^{n} LH(i,j) + \sum_{i=1}^{m}\sum_{j=1}^{n} HL(i,j) + \sum_{i=1}^{m}\sum_{j=1}^{n} HH(i,j) \right) \qquad (6)$$

$$Q = Sum/4$$

The subband, for which the summation of pixel intensities is greater than Q, is selected for watermark embedding.

3.2 SVD Implementation and Watermark Embedding

Singular value decomposition is applied on selected subband. Here, the selected band (e. g. LL subband) is decomposed into three matrices *s(i,j)*, *u(i,j)* and *v(i,j)*. Extracted singular value matrix *s(i,j)* is used to embed the watermark *W(i,j)*, other two matrices are used to generate secret key.

$$SSub(i,j) = u(i,j)s(i,j)v(i,j)$$

$$s_W(i,j) = s(i,j) + \alpha W(i,j) \qquad (7)$$

$s_W(i,j)$ is watermarked singular value vector, α is scaling factor of watermark, and SVD for this is obtained by:

$$s_W(i,j) = u_1(i,j)s_W^*(i,j)v_1(i,j)$$

u_1, s_W^*, v_1 are the decomposed vectors after watermarking and $SSub_W$ is called watermarked image as follows:

$$SSub_W(i,j) = u(i,j)s^*{}_W(i,j)v^t(i,j) \qquad (8)$$

3.3 Reconstruction of Watermarked Image

Following steps are used to reconstruct the watermarked image.

1st step: To reconstruct the watermarked image, inverse lifting wavelet transform is used by using lifting coefficients.

2nd step: HH and HL subbands of dimension *(m/2)*x*(n/2)* are merged to form H band of image, having dimension *m*x*(n/2).*

3rd step: LH and LL subbands of dimension *(m/2)*x*(n/2)* are merged to form L band of image, having dimension *m*x*(n/2).*

4th step: H and L subbands of dimension *m*x*(n/2).* are merged to form watermarked image of dimension *m*x*n*.

Where, $SSub_W(i,j)$ is watermarked image in LWT domain, after inverse process of LWT the watermarked image $X^*{}_W(m,n)$ is reconstructed.

3.4 Watermark Retrieval

The watermarked image is made available on internet, it gets attacked by different attacks *A*(m, n)*. To retrieve the watermark from attacked image, firstly LWT is applied on attacked image to obtain subbands. Then intensity of subbands is compared with the Q. The selected subband (having summation of subband intensity greater than Q) is used to extract the watermark. Singular values (9) are decomposed from this subband and SVD is carried out for this singular values to obtain D_{LLW}^*. Finally watermark is retrieved using (10) below.

$$SSub_w{}^*(i,j) = u_{LLW}^*(i,j)\, s_{LLW}^*(i,j)\, v_{LLW}^*(i,j) \qquad (9)$$

$$D_{LLW}^*(i,j) = u_1(i,j)\, s_{LLW}^*(i,j)\, v_1(i,j)$$

Where, u_1 and v_1 are the watermarked image vectors after watermark embedding. $dW^*(i,j)$ is the difference of watermarked image SVD and singular value of original image.

$$dW^*(i,j) = ((D^*_{LLW}(i,j) - s(i,j))/\alpha) \qquad (10)$$

Where, dW^* is the retrieved watermark.

$$dW^*(i,j) = \begin{cases} dW^*(i,j) > 0 & W^* = 255 \\ dW^*(i,j) \le 0 & W^* = 0 \end{cases}$$

3.5 Robustness of Proposed Algorithm

The conventionally employed DWT uses down and up sampling which leads to loss of information. Whereas in LWT, there is no down and up sampling as such which increases the CRC values leading to highly robust watermark. Also, convolution is used in the DWT to transform the image in frequency domain this increase computation complexity and which is also a source of loss of information. In LWT split and merge process is used so computation complexity is reduced by 50% [13]. This fact also helps in improvement of robustness in watermarking.

4. RESULTS

4.1.Experimental Setup

For demonstrating the performance of the proposed watermarking algorithm following measures are carried out, A performance measuring parameter CRC is estimated. Fidelity of watermarked image is evaluated by computing PSNR and also, displayed for visual check. Watermarked images after different attacks and retrieved watermark after attacks are also displayed for study. To explore the performance of the proposed algorithm, experiments are performed on different images viz; Pepper, Rose, Mandrill of size 512x512, and Cameraman of size 256x256.

4.2.PSNR

Fig.4.a shows original images and Fig.4.b, shows images after watermark is embedded in it. Fidelity of watermarked image is very good. No degradation of image is observed visually (refer Fig.4.a. and Fig.4.b), and computed PSNR is also high. In Table 1, PSNR result obtained with proposed method for three standard images are compared with DWT-SVD based method [6].

In addition, the PSNR for rose and cameraman images with the proposed method are observed as 88.49, and 92.45 respectively. This shows that fidelity of the watermarked image is improved. Author's identity mark that is, 'digital signature' is used as watermark for convenience to recognize and authenticate the owner of the digital information. The size of digital signature watermark is taken to be 25% of the original image shown in fig. 4.c. The retrieved watermark from pepper image without attack by algorithm is shown in fig.4.d. The scaling factor of watermark is set to 0.1 to get good results of fidelity and correlation coefficient.

4.3.Results after Different Attacks

Robustness test is carried out by applying different intentional and unintentional attacks as given below.

4.3.1Rotation and Compression Attack

A 50^0 rotation angle is used to study effect of rotation attack. Fig. 5.a. and 5.b shows the watermarked image after rotation attack and retrieved watermark after attack respectively. The correlation coefficient (between original and retrieved watermark) by proposed method is 0.9737 indicating high robustness. Fig.5.c shows compression attack on image, which is most common manipulation in digital image processing. In this JPEG compression is used and compression ratio is 75.5. Fig.5.d. shows that even after a heavy compression, the retrieved watermark is almost unchanged. The CRC is 0.9738.

4.3.2Filter Attack

To obtain the smooth image, low pass filter is applied on watermarked image shown in fig.5.e. Retrieved watermark after this attack is shown in fig.5.f. and CRC by this attack is observed to be 0.9027. Fig.6.a. shows high pass filtered image. After this attack watermark is retrieved and shown in fig.6.b. The CRC after attack is 0.9788. This shows that proposed LWT-SVD method is more robust against high pass filter attack than low pass filter attack.

4.3.3 Transform Rotation and Quantization Attack

Image is attacked by transform rotation attack and robustness is tested. Fig. 6.c. shows transformed and rotated image and fig.6.d. shows retrieved watermark after attack. Computed correlation coefficient is 0.9917. This shows high robustness against this attack. Quantization is widely used signal processing. This processing is done at the time of storing data in the computers. Fig.6.e. shows the image after quantization and fig.6.f. shows retrieved watermark after attack. Retrieved watermark is recognisable, and the correlation coefficient is 0.9254.

4.3.4 Gaussian White Noise and Contrast Stretch Attack

Fig. 7.a. shows watermarked image after adding of Gaussian white noise. The mean of the additive Gaussian white noise is zero and its variance is 0.01. By performing the watermark detection, we obtain the watermark shown in fig.7.b. The correlation coefficient between them is 0.8791. The contrast stretch is the application of image enhancement. It adjusts the contrast of an image by linearly scaling the pixel values between upper and lower limits. Fig.7.c. shows the image after contrast stretch and fig.7.d. shows the retrieved watermark after contrast stretch attack, which is visually exact replica of original watermark and CRC is 0.9763.

4.3.5 Scaling Shrink and Cropping Attack

Fig. 7.e. shows watermarked image after shrinking of the image. Fig.7.f. shows the retrieved watermark after shrinking of image is similar to original watermark. CRC of proposed method is 0.7744. Cropping is the process of selecting and removing a portion of an image to create focus or strengthen its work of art. It is lossy operation and frequently used in real life. Cropping an image is done by either hiding or deleting the rows and columns. For this attack, 50% of the watermarked image is cropped as shown in fig.8.a. and then watermark is extracted as shown in fig.8.b. The retrieved watermark shows existence of owner's identity after attack and correlation coefficient is 0.9532.

4.3.6 Sharpen and Power Transform Attack

The boundary of an object in a gray scale image is located where the sharp changing of the gray level happens. When human vision senses the object, it recognizes the outlines by enhancing the edge beyond its true natural appearance. The mechanism of this enhancement in the vision system decreases the dark side of the edge and increases the bright side of the edge at the same time. Therefore, it makes the edges of the object more obvious. Fig.8.c. shows the sharpened watermarked image and fig.8.d shows the retrieved image after attack. CRC calculated is 0.9729, which shows that the watermark is robust. Image is transformed by gamma correction factor. Changing the value of gamma, we obtain a family of transformation curves. Non linearity encountered during image capturing, printing and displaying can be corrected using gamma correction. Hence gamma correction is important if the image needs to be displayed on the computer. Power transformation can also be used to improve the dynamic range of an image. Fig.8.e. shows power transformation attacked image and fig.8.f shows retrieved watermark after attack. It is observed that retrieved watermark is similar to original watermark and CRC is 0.9746.

Table 1.Comparison of PSNR for standard images

Standard Images	PSNR for DWT-SVD [6] Method	PSNR for LWT-SVD Proposed Method
Pepper	44.12	92.00
Mandrill	40.93	90.87
Lena	43.65	95.82

4.3.7 Gaussian White Noise and Zooming Attack

Addition of noise is another method to estimate the robustness of the watermark. Generally, image is degraded and distorted by addition of noise. Robustness against additive noise is estimated by degrading the watermarked image with adding the noise as shown in fig.9.a. The watermark is retrieved and correlated to the original watermark. It is observed that the correlated value is above 0.8791. The extracted logo is shown in fig. 9.b. and it can be observed that extracted logo is recognizable.

Table-2: CRC before attack by proposed method (Alpha=0.1)

Different Images(512x512)	CRC
Pepper	0.9788
Mandrill	0.9788
Rose	0.9788
Lena	0.9788
Cameraman	0.9606

Table-3: Comparison of CRC after different attack with previous method

Attacks on Pepper Image	DWT-SVD [6]	LWT-SVD Proposed
Rotation (50°)	0.3309	0.9737
Compression	(80:1) 0.9922	(75.7:1) 0.9788
Gaussian White Noise	0.2843	0.8791
Scaling Shrink	0.5648	0.7744
Cropping (1/4)	0.3840	0.9532
Sharpen	0.6784	0.9729
Median Filter (13×13)	−0.3233	0.9732
Average filter (13×13)	−0.3696	0.8726
Histogram Equalization	0.8620	0.9744
Motion Blur	−0.3280	0.9788

Zoom out is applied on the watermarked image as shown in fig.9.c and retrieved watermark is observed in fig.9.d. Visually the retrieved watermark is exact replica of original watermark.

4.3.8Median Filter and Average Filter

The results are observed after applying 13×13 median filtering and average filtering. These are one of the most common manipulations in digital images. Fig.9.e and fig.10.a show the watermarked images after average and median filtering attacks respectively. It can be observed that watermark retrieved after average filter attack is similar to original watermark shown in fig.9.f and CRC is 0.9732. It shows good robustness compared to the DWT-SVD [6] method. Retrieved watermark after average filter attack is as shown in fig.10.b. CRC by proposed LWT-SVD method is 0.8726.

4.3.9 Histogram Equalization and Motion Blur Attack

We also tested proposed watermarking method for histogram equalization, and motion Blur. Fig.10.c and fig10.d show the result for Histogram Equalization and Motion Blur respectively. Proposed method is fairly resilient against Histogram Equalization as observed in the obtained results. Fig.10.e and 10.f show that extracted watermark is the exact replica of the original watermark.

4.4. Active Attacks

The active attacker tries to remove the watermark or make it undetectable. This type of attack is critical for many applications, including owner identification, proof of ownership, fingerprinting, and copy control [17],[18]. The proposed watermarking scheme provides security against the active attacks in four stages. At the first stage of security, the active attacker need to know beforehand the lifting wavelet transformation and number of levels the image transformation has been carried out. At the second stage of security, he must have prior information about the band in which the watermark is embedded. This is quite difficult. Third stage security is he must know that the watermark is embedded in singular values of the band. Fourth stage of security is the scaling of the watermark which is embedded in the image. Unless the active hacker passes all the above stages of security it is impossible to tamper the watermark embedded in the image.

Similarly, the fourth stage security, provided by the proposed method, makes the method robust against the ambiguity attack. This is so because the attacker here needs to create reference image from watermarked image, available to him, as the first step. However this is strictly prohibited on account of the security provided against tampering by the proposed method as discussed above.

4.5. Comparison of Correlation Coefficient

In Table 2 the comparison of correlation coefficient (CRC) computed between the original watermark and retrieved watermark before attack for 5 different images are tabulated. In Table 3, ten different attacks are experimented on pepper image. CRC between original watermark and retrieved watermark is computed and tabulated. These results are compared with DWT-SVD method [6] by Bhatnagar. It is observed that the watermarking by proposed LWT-SVD based method is more robust as compared with the earlier approach. In table 4, in addition to earlier ten attacks, further eight attacks i.e. in total eighteen attacks are applied on 4 different images. CRC is computed between original watermark and retrieved watermark to check how robust the watermark is after several attacks. These CRC values confirm that with proposed method there is less degradation of retrieved watermark after attacks.

5. CONCLUSION

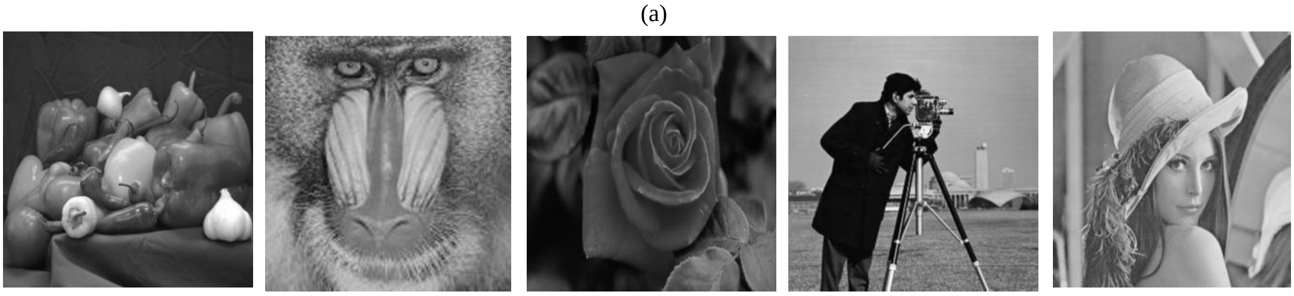
A novel robust digital image watermarking method based on LWT-SVD is proposed. To investigate the robustness of proposed algorithm, five different images and eighteen different intentional and unintentional attacks were employed. PSNR values are estimated for all the five images. Comparing these PSNR values with that obtained by earlier approach based on DWT-SVD [6], it can be concluded that the fidelity of the watermarked image is improved with the proposed method. Similarly the correlation coefficient between retrieved watermark and original watermark is estimated for all the images. From these coefficients it is observed that the watermark retrieval is highly efficient with proposed method. Here it can be concluded that the proposed algorithm has two-fold advantages, firstly there is an improvement in PSNR values (with no degradation of watermarked image quality) and secondly there is simultaneous improvement in the CRC values (improved robustness of watermark).

This indicates that the quality of image after watermarking remains high and strength of the retrieved watermark i.e. robustness is also high at the same time. This is a highly desirable property in digital image watermarking, which is achieved with the proposed algorithm as compared to the earlier approach.

The above said advantages of proposed method are possible because of the use of LWT. The LWT results in getting good reconstruction of watermark embedded image, increasing smoothness and decreasing aliasing effects since down sampling and up sampling is avoided in lifting scheme

Also SVD helps to maintain the fidelity of the watermarked image and it reconstructs the watermark more efficiently. In proposed approach, fixed orthogonal bases (LWT) and non fixed-orthogonal bases (SVD) are combined, which results in enhancement of intactness, fidelity and robustness of watermarking that makes the watermark invariant to all types of digital image processing as well as intentional attacks.

(a)



(b)

Fig. 4. Digital watermarking by LWT-SVD method. (a) Original images (Pepper, Mandrill, Rose, Cameraman and Lena) (b) Watermarked images respectively

(c) (d)

Fig.4. (c) Original digital signature watermark
(d) Retrieved watermark from pepper image by algorithm without attack

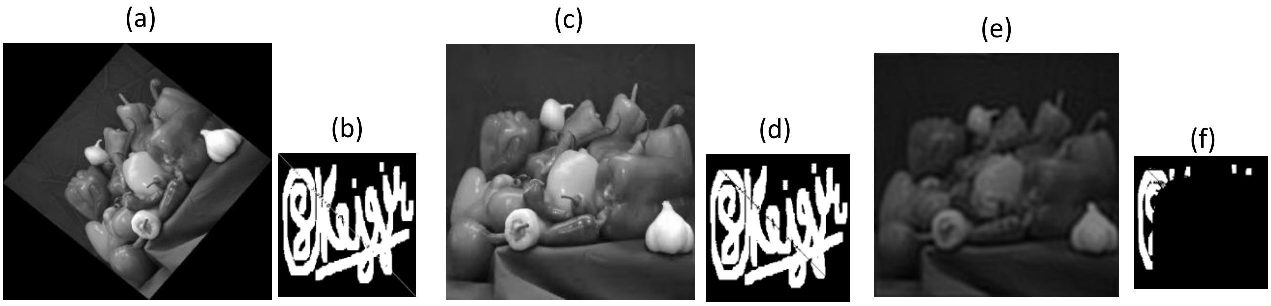


Fig.5. (a) Rotated image by rotation 50^0 (b) Retrieved watermark after 50^0 rotation attack (c) Compressed image, CR=75.5 (d) Retrieved watermark after this attack(e) Image after low pass filtered attack (f) Retrieved watermark after LPF attack

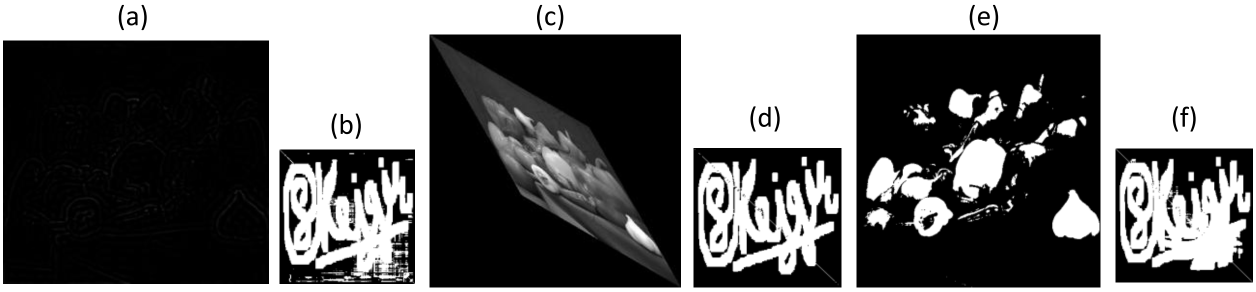


Fig.6. (a) Image after high pass (b) Retrieved watermark after HPF attack (c) Transform rotation attacked image. (d) Retrieved watermark after transform rotation (e) Image after quantization attack (f) Retrieved watermark after quantization

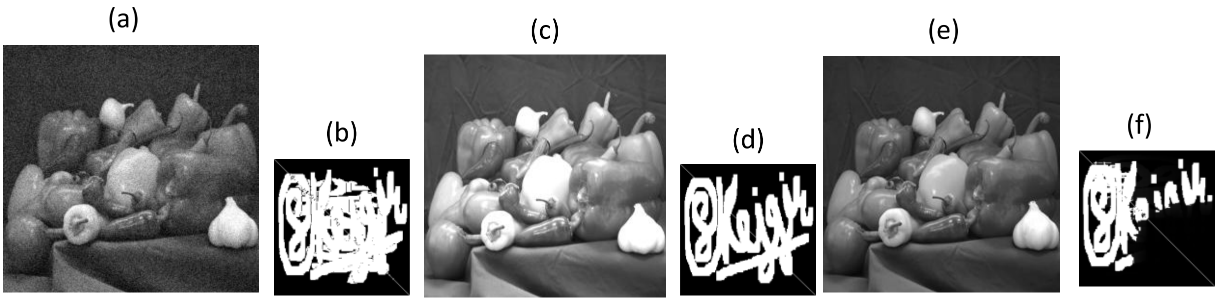


Fig.7. (a) Image after Gaussian white noise attack (b) Retrieved watermark after this attack (c) Image after contrast stretch attack (d) Retrieved watermark after contrast stretch.(e) image after shrink attack (f) Retrieved watermark

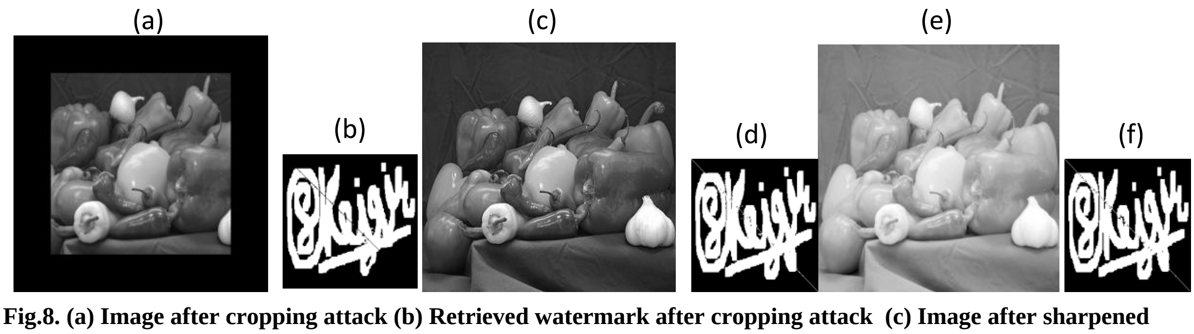


Fig.8. (a) Image after cropping attack (b) Retrieved watermark after cropping attack (c) Image after sharpened attack (d) Retrieved watermark after sharpen attack (e) Power transformed image (f) Retrieved watermark after

Table-4: CRC after different attacks by proposed method (Alpha=0.1)

Different Attacks	CRC for different images				
	Pepper (512x512)	**Mandrill (512x512)**	**Rose (512x512)**	**Lena (5121x512)**	**Cameraman (256x256)**
Rotation (50°)	0.9737	0.8710	0.9752	0.9756	0.9540
Compression	(75.7:1) 0.9738	(75.9:1) 0.9572	(60.9:1) 0.9681	(77:1) 0.9742	(16.2:1) 0.9515
Transform Rotation	0.9917	0.9790	0.9865	0.9893	0.9834
Low Pass Filter	0.9027	0.9205	0.9228	0.9657	0.8845
High Pass Filter	0.9702	0.9554	0.9752	0.9314	0.9533
Quantization attack	0.9254	0.7952	0.8732	0.9254	0.9422
Gaussian White Noise	0.8791	0.8152	0.8441	0.9046	0.9402
Contrast Stretch	0.9763	0.9763	0.9763	0.9763	0.9566
Scaling Shrink	0.7744	0.8060	0.7594	0.7746	0.7147
Cropping (1/4)	0.9532	0.6661	0.8523	0.9542	0.8591
Sharpen	0.9729	0.9457	0.9734	0.9730	0.9466
Power-Transform	0.9746	0.9633	0.9746	0.9760	0.9540
Zoom	0.9674	0.9572	0.9676	0.9669	0.9338
Gaussian Filter Noise	0.9741	0.9759	0.9735	0.9741	0.9479
Median Filter (13×13)	0.9732	0.9162	0.9739	0.9720	0.9422
Average filter (13×13)	0.8726	0.8127	0.8692	0.8714	0.8527
Histogram Equalization	0.9744	0.9738	0.9740	0.9743	0.9447
Motion Blur	0.9788	0.9375	0.9733	0.9741	0.9447

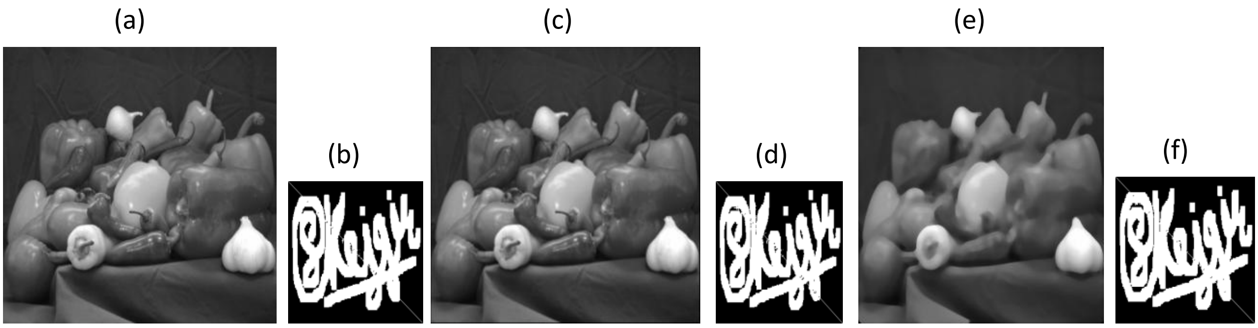


Fig.9. (a) Gaussian filter 16*16, (b) Retrieved watermark after Gaussian filter (16*16) (c) Zoomed image (d) Retrieved watermark after zoom attack(e) Image after median filter (13*13) attack (f) Retrieved watermark after median filter

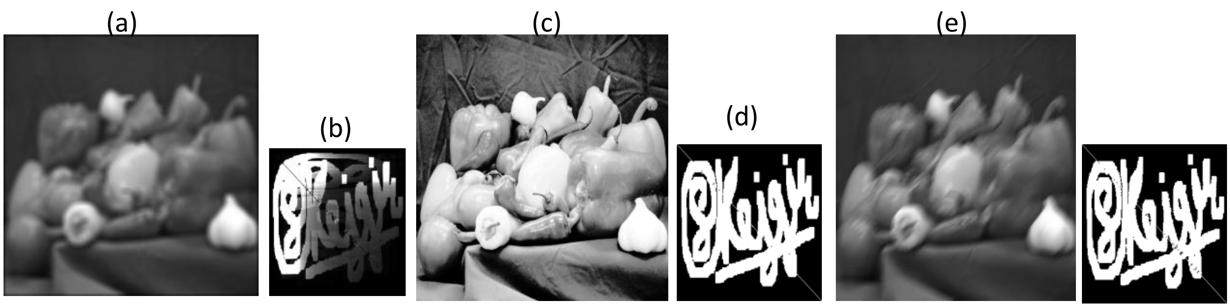


Fig.10. (a) Watermarked image after Average filter (13*13) (b) Retrieved watermark after this attack (c) Histogram equalized image (d) Retrieved watermark after histogram (e) Motion blurred image (f) Retrieved watermark after motion blurred

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