An Improved Imperceptibility and Robustness of 4x4 DCT-SVD Image Watermarking Using Modified Entropy

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***Abstract*—A digital protection against unauthorized distribution of digital multimedia is highly on demand. Digital watermarking is a defence in multimedia protection for authorized ownership. This paper proposes an improved watermarking based on 4×4 DCT-SVD blocks using modified entropy in image watermarking. A modified entropy is used to select unnoticeable blocks. The proposed watermarking scheme utilizes the lowest entropy values to determine unnoticeable regions of the watermarked image. This paper investigates the relationship between $U_{(2,1)}$ and $U_{(3,1)}$ coefficients of the U matrix 4×4 DCT-SVD in image watermarking. The proposed watermarking scheme produces a great level of robustness and imperceptibility of the watermarked image against different attacks. The proposed scheme shows the improvement in terms of structural similarity index and normalized correlation of the watermarked image.**

***Index Terms*—Modified Entropy; Discrete Cosine Transform; Imperceptibility; Watermark Embedding; Robustness.**

I. Introduction

The advancement of multimedia technology has contributed to the unauthorized distribution of digital images. This leads to provide ownership authentication and multimedia protection against unapproved redistributing multimedia data. Digital image watermarking is an alternative solution to preserve the ownership from distribution and duplication of digital images. Digital image watermarking is a method which aids in preventing the copying of digital data and protects it by imperceptibly hiding a mark that has authorized information into the original data.

Image watermarking has been designed in spatial or frequency methods. Image watermarking with directly altering pixels in watermarking scheme leads to easy and low computational cost [1–2]. Image watermarking schemes based on frequency domain produce more robust than image watermarking with spatial domain [3]. The embedded watermarks in the frequency domain are distributed irregular over the image when it is inversely transformed in the spatial domain. This scheme is able to improve watermark robustness while still maintaining their imperceptibility [4].

Frequency transforms have been applied in image watermarking schemes such as DCT [5–8], SVD [9-10], Tchebichef moment transform (TMT) [11-12] and discrete wavelet transforms (DWT) [13]. DCT has been used in image compressions [14-17], image watermarking, steganography image and other image processing applications. DCT is used as the basis of digital watermarking due to its advantages such as high-energy compaction, less computational algorithms, high robustness and easy implementation in watermarking applications.

In other hands, DWT is more superior to DCT such as in [18]. However, in real application DWT requires high computational cost and uses wavelet transform. Thus, the DWT also produces shift invariant and it skips the down sampling process of each level in the DWT filtering. Otherwise, SVD is most commonly used as a transformation technique in watermarking because of its strong properties [19]. SVD is a technique for getting geometric features from an image. The combination of DCT and SVD can elevate the performance of watermarking scheme [3].

This paper proposes 4×4 DCT-SVD watermarking scheme using modified entropy. The modified entropy is used to select blocks of the image which aid to achieve a maximum robustness and it does not produce un-noticeable distortion for embedded watermarks. A watermarking scheme based on 4×4 DCT-SVD is proposed to improve the capacity of embedded watermarks. The smaller selected blocks have potential to achieve high imperceptibility. The number of selected blocks using modified entropy has to match the number of watermark bits. This paper investigates the impact of embedded watermarks in the U matrix of 4×4 SVD in the first column in terms of the quantization step. In addition, we apply image encryption to protect the rightful ownership.

II. Background

The characteristics of an image watermarking are its imperceptibility, robustness, watermark capacity, and watermark security [18]. The hybrid DCT-SVD has been developed in many digital image watermarking. The watermark insertion in the values (S) of the matrix SVD produces false positive issue. Researchers investigate the embedded watermarks in the values (U) or (V) of the matrix SVD [19-21].

Lai's watermarking scheme [21] has investigated the relation between $U_{3,1}$ and $U_{4,1}$ of U matrix on 8×8 DCT-SVD. This scheme allows attackers to easily extract the watermark image. In the watermarking recovery, there is no rightful ownership protection. Additionally, the actual owner is able to extract the watermark from arbitrary images. These issues should be considered before we apply Lai's scheme [21] for the rightful owners in watermark applications. Moreover, Lai's scheme has not been investigated the trade-off between imperceptibility and robustness. The threshold in Lai's scheme plays a key role to determine the imperceptibility of watermarked images. The Lai's watermarking scheme can achieve a good quality level of PSNR values. The watermark's robustness produces a great level of bit correction rate (BCR). However, the watermark recovery is not resistance towards Gaussian noise and median filter.

This paper proposes 4×4 DCT-SVD watermarking scheme by investigating $U_{(2,1)}$ and $U_{(3,1)}$ coefficients of the U matrix 4×4 DCT-SVD. DCT-SVD is used instead of DWT, because DCT achieves less computational cost and has easy implementation towards the rightful owner's applications. The two-dimensional DCT of an image A is defined:

$$B_{pq} = \alpha_p \beta_q \sum_{m=0}^{M-1} \sum_{n=0}^{N-1} A_{mn} \cos\frac{\pi(2m+1)p}{2M} \cos\frac{\pi(2n+1)q}{2N}, \quad (1)$$

for $p = 0, 1, 2, \ldots, M-1$ and $q = 0, 1, 2, \ldots, N-1$ where

$$\alpha_p = \begin{cases} \frac{1}{\sqrt{M}}, & p = 0 \\ \sqrt{\frac{2}{M}}, & p > 0 \end{cases} \quad \beta_q = \begin{cases} \frac{1}{\sqrt{N}}, & q = 0 \\ \sqrt{\frac{2}{N}}, & q > 0 \end{cases} \quad (2)$$

The inverse of discrete cosine transform can be computed by:

$$A_{pq} = \sum_{m=0}^{M-1} \sum_{n=0}^{N-1} \alpha_p \beta_q B_{mn} \cos\frac{\pi(2m+1)p}{2M} \cos\frac{\pi(2n+1)q}{2N}, \quad (3)$$

for $p,q = 0, 1, 2, 3$. The singular value decomposition of D is given by $D = USV^T$, where singular vectors U and V are orthogonal matrices and singular vector S is a diagonal matrix (λ_i) of singular values λ_i=1, 2, 3, 4 arranged in decreasing order.

III. PROPOSED WATERMARKING SCHEME

These experiments use four grayscale images from CVG-UGR image database [22]. Four grayscale images which have 512×512 pixels are shown in Figure 1. The proposed watermarking scheme is tested with two binary images of different sizes. The watermark images are depicted in Figure 2.

The binary watermark images of different sizes are used to be inserted into four host images. Before the watermark is being inserted, the watermark binary images are encrypted by applying logical XOR operation between a private key image generation and watermark binary image. A key image generation has unique random pixel values, 8 bits/pixel as shown in Figure 3. Only the actual owner that has a private key as presented by an image 8 bits/pixel can extract the watermark image. The insertion and extraction of the watermarking process are depicted in Figures 4 and 5.

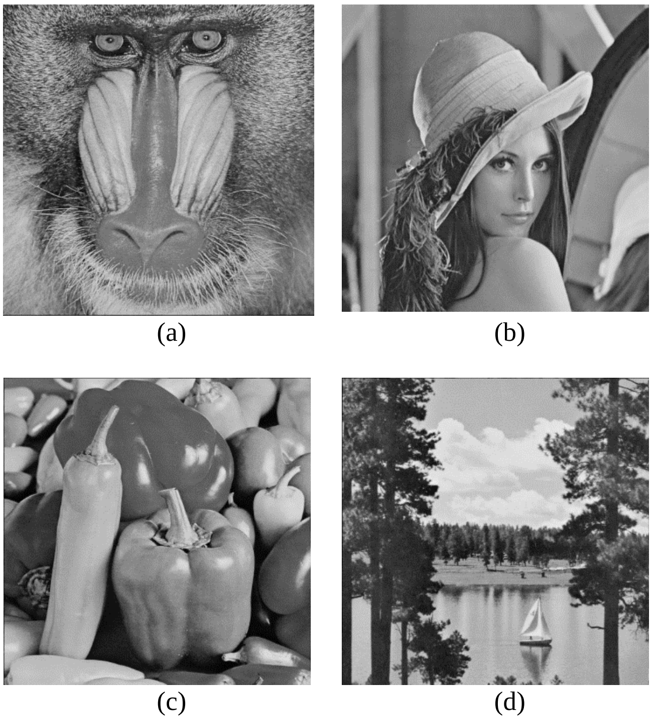

Figure 1: Four images (a) Baboon, (b) Lena, (c) Peppers, (d) Sailboat, 512×512, 8 bits/pixel.

Figure 2: Original watermark image: (a) watermark image A with 48×48 pixels and (b) watermark image B with 32×48 pixels.

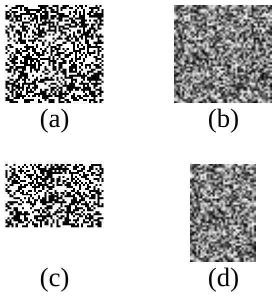

Figure 3: (a) encrypted watermark A, 48×48 pixels, 1 bit/pixel (b) key of watermark A, 48×48 pixels, 8 bits/pixel (c) encrypted watermark B, 32×48 pixels, 1 bit/pixel (d) key of watermark B, 48×32 pixels, 8 bits/pixel.

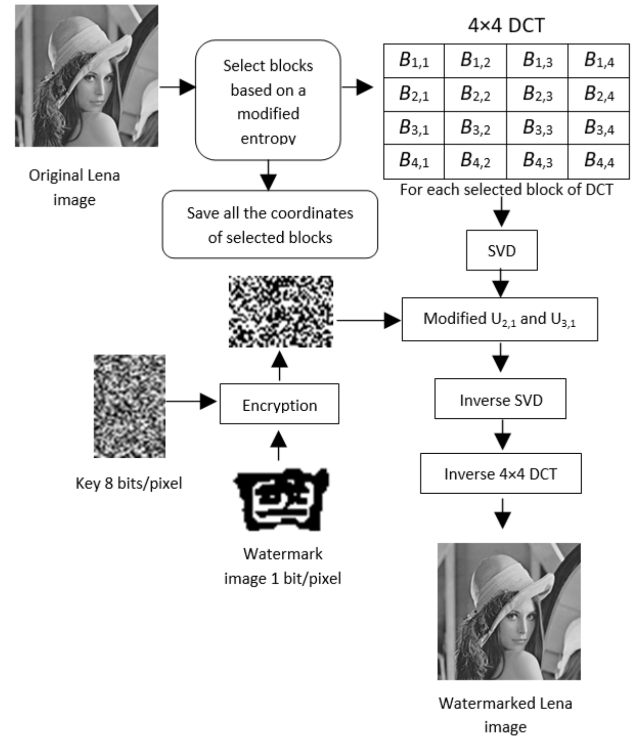

Figure 4: Insertion steps

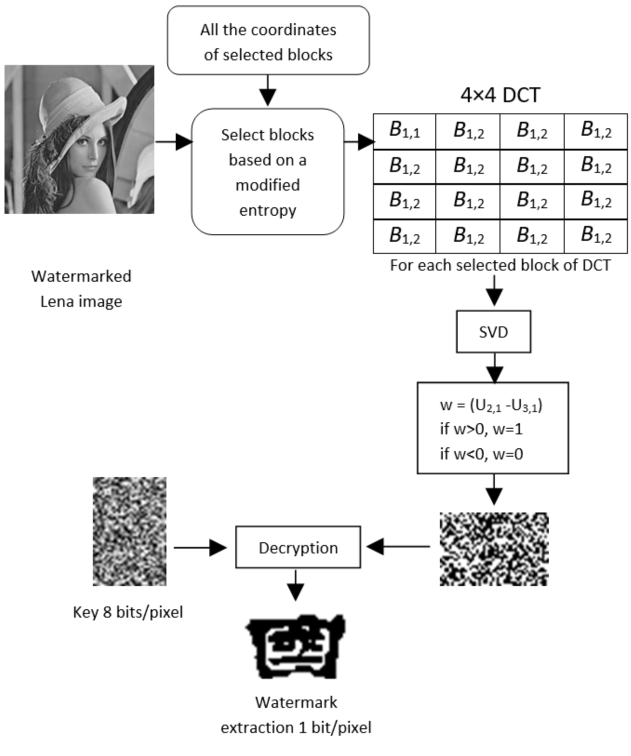

Figure 5: Extraction steps

A. Watermark Insertion

Embedding watermark sequence is given as follows:

Step1: Original image is first divided into 4×4 block image pixels.

Step2: Calculate the modified entropy for each image block. The modified entropy is defined by:

$$E = -\sum_{i=1}^{n} p_i \log_2(p_i) + p_i \exp^{1-p_i} \tag{4}$$

p_i denotes the occurrence probability of an event i with $0 \le p_i \le 1$. The values obtained from modified entropy are sorted, then the lowest values are utilized to select image blocks for the embedded watermark.

Step3: The selected blocks are transformed by 4×4 DCT.

Step4: Apply SVD to 4×4 DCT coefficients. The results of SVD implementation by $U_{(4\times4)}$ is given as follows:

$$U = \begin{bmatrix} U_{(1,1)} & U_{(1,2)} & U_{(1,3)} & U_{(1,4)} \\ U_{(2,1)} & U_{(2,2)} & U_{(2,3)} & U_{(2,4)} \\ U_{(3,1)} & U_{(3,2)} & U_{(3,3)} & U_{(3,4)} \\ U_{(4,1)} & U_{(4,2)} & U_{(4,3)} & U_{(4,4)} \end{bmatrix} \tag{5}$$

For each selected block, the first column coefficients $U_{(2,1)}$ and $U_{(3,1)}$ are modified based on watermark binary values.

Step5: For each selected block, $U_{(2,1)}$ and $U_{(3,1)}$ coefficients are changed and then compared to the threshold. If the watermark binary image is equal to 1, the coefficients of ($U_{(2,1)}$-$U_{(3,1)}$) must be a positive value and greater than the threshold (T). Otherwise, if the watermark is 0, the relation ($U_{(2,1)}$-$U_{(3,1)}$) must be a negative value then it should greater than the threshold (T). These conditions are violated, the coefficients of $U_{(2,1)}$ and $U_{(3,1)}$ must be modified based on the rules as given:

$$y = \frac{\left(\left|U_{(2,1)}\right| + \left|U_{(3,1)}\right|\right)}{2}, \tag{6}$$

$$\text{if } w_i = 1, \begin{cases} \tilde{U}_{(2,1)} = y + T/2 \\ \tilde{U}_{(3,1)} = y - T/2 \end{cases},$$

$$\text{if } w_i = 0, \begin{cases} \tilde{U}_{(2,1)} = y - T/2 \\ \tilde{U}_{(3,1)} = y + T/2 \end{cases},$$

where w_i denotes the watermark of i pixel with w equal to 0 or w equal to 1. $\tilde{U}$ represents a modified coefficient.

Step6: Inverse the SVD, then inverse the DCT for all selected blocks to generate a watermarked image.

B. Watermark Recovery

Extracting watermark sequence is described as follows:

Step1: Watermarked image is first divided into 4×4 block image pixels.

Step2: Ascending values of modified entropy are used to identify the selected block for watermark embedding.

Step3: Apply 4×4 DCT to obtain DCT coefficients for each selected blocks.

Step4: Implement SVD to DCT coefficients of the selected block.

Step5: The relation ($U_{(2,1)}$-$U_{(3,1)}$) of U matrix is calculated. If the result is positive, then the watermark recovery is 1, otherwise, the watermark is 0.

C. Watermarked Evaluation

The watermarked imperceptibility is measured by structural similarity (SSIM) index and reconstruction errors. Reconstruction errors are calculated by measuring the difference between watermarked pixels and original pixels. SSIM is a method which measures the quality by capturing the similarity and it can be computed by:

$$SSIM(x,y) = [l(x,y)]^{\alpha} \cdot [c(x,y)]^{\beta} \cdot [s(x,y)]^{\gamma} \quad (7)$$

where α>0, β>0, γ>0. A detail description can be found in [23]. Robustness of watermark recovery is estimated by normalized correlation (NC) that measures the correlation between the watermark pixels extraction and original watermark pixels. The NC is given as follows:

$$NC = \frac{\sum_{i=1}^{M}\sum_{j=1}^{N} W(i,j).W^{*}(i,j)}{\sqrt{\sum_{i=1}^{M}\sum_{j=1}^{N} W(i,j)^{2} \sum_{i=1}^{M}\sum_{j=1}^{N} W^{*}(i,j)^{2}}} \quad (8)$$

where $W(i, j)$ represents original watermark pixels, $W^{*}(i, j)$ denotes watermark recovery and $M \times N$ represents the watermark size.

IV. Experimental Results

The different watermark sizes are embedded into four host images. The imperceptibility and robustness are determined by the quantization step, it measures the tradeoff between them. The robustness of watermarked image is measured by NC, whereas the imperceptibility is measured by SSIM. We investigate the optimal threshold of Lai's watermarking scheme and the proposed 4×4 DCT-SVD using modified entropy. The optimal threshold of Lai's scheme can be obtained by T = 0.019 as shown in Figure 6. The proposed watermarking scheme can achieve the tradeoff between robustness and imperceptibility with T = 0.42. Figure 7 shows the relationship between $U_{(2,1)}$ and $U_{(3,1)}$ on 4×4 DCT-SVD by quantization steps.

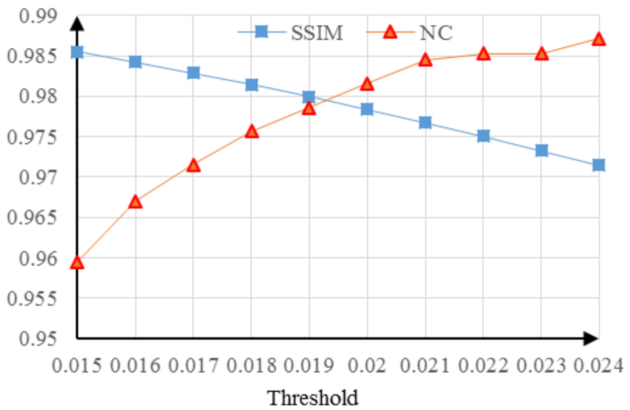

Figure 6: Relationship between imperceptibility and robustness of modified $U_{(3,1)}$ and $U_{(4,1)}$ on 8×8 DCT-SVD.

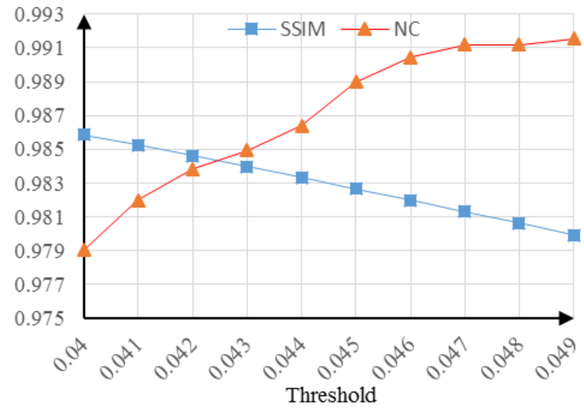

Figure 7: Relationship between imperceptibility and robustness of modified $U_{(2,1)}$ and $U_{(3,1)}$ on 4×4 DCT-SVD.

Table 1
Comparison of Lai's Scheme and Proposed Scheme in terms of ARE, PSNR, SSIM Using Watermark A

Images	Lai's Scheme [21] T = 0.019			Propose T = 0.042		
	ARE	PSNR	SSIM	ARE	PSNR	SSIM
Baboon	2.794	30.984	0.959	0.821	35.196	0.988
Lena	0.988	43.126	0.980	0.559	42.763	0.985
Pepper	1.084	39.918	0.977	0.506	43.097	0.987
Sailboat	1.524	38.066	0.965	0.712	40.784	0.976
Average	1.598	38.024	0.970	0.650	40.460	0.984

Table 2
Comparison of Lai's Scheme and Proposed Scheme in terms of ARE, PSNR, SSIM Using Watermark B

Images	Lai's Scheme [21] T = 0.019			Propose T = 0.042		
	ARE	PSNR	SSIM	ARE	PSNR	SSIM
Baboon	1.544	33.460	0.978	0.531	37.118	0.992
Lena	0.649	45.455	0.985	0.381	44.334	0.989
Pepper	0.654	43.866	0.985	0.343	44.682	0.991
Sailboat	0.860	42.686	0.976	0.486	42.349	0.983
Average	0.927	41.367	0.981	0.435	42.121	0.989

Tables 1 and 2 show ARE, PSNR, SSIM performances of Lai's scheme and our scheme using different watermark sizes. The quantitative measurement results show that our scheme produces less absolute reconstruction errors compared to Lai's scheme. SSIM values of the proposed scheme are higher than Lai's scheme. The embedded watermarks in smaller block produce high watermarked image quality. The proposed smaller blocks taken can increase the capacity of watermark bits.

Referring to Table 2, when the watermark size is small, it improves the reconstruction errors of the watermarked image. The proposed scheme shows that the average of four watermarked images produces better image quality than Lai's scheme. The watermarked images are tested against seven types of attacks, e.g., Gaussian noise, JPEG compression, Gaussian low pass filter, salt & pepper, median filter, sharpening, and cropping. The comparison normalized correlation of watermark recovery is listed in Tables 3 and 4 with different sizes of watermark images.

Table 3
Comparison of Lai's Scheme and Proposed Scheme in terms of NC Using Watermark A

Attacks	Lai's Scheme [21] T = 0.019		Propose T = 0.042	
	Baboon	Lena	Baboon	Lena
Gaussian noise 0.001	0.890	0.708	0.973	0.981
JPEG compression	0.994	0.979	0.989	0.984
Gaussian low pass filter [3 3]	0.865	0.866	0.959	0.990
Salt and pepper noise 0.005	0.920	0.900	0.979	0.982
Median filter [3 3]	0.812	0.834	0.918	0.986
Sharpening	0.938	0.913	0.990	0.993
Cropping centre 12.5%	0.952	0.980	0.924	0.991
Average	0.910	0.883	0.962	0.987

Based on Tables 3 and 4, the proposed image watermarking scheme can perform in a good level of watermark recovery with different sizes of watermark images. It shows that the proposed watermarking scheme offers more robust than Lai's scheme. The visual watermark recovery after its attacks is shown in Figure 8. The proposed watermarking scheme can achieve great robustness from different types of attacks.

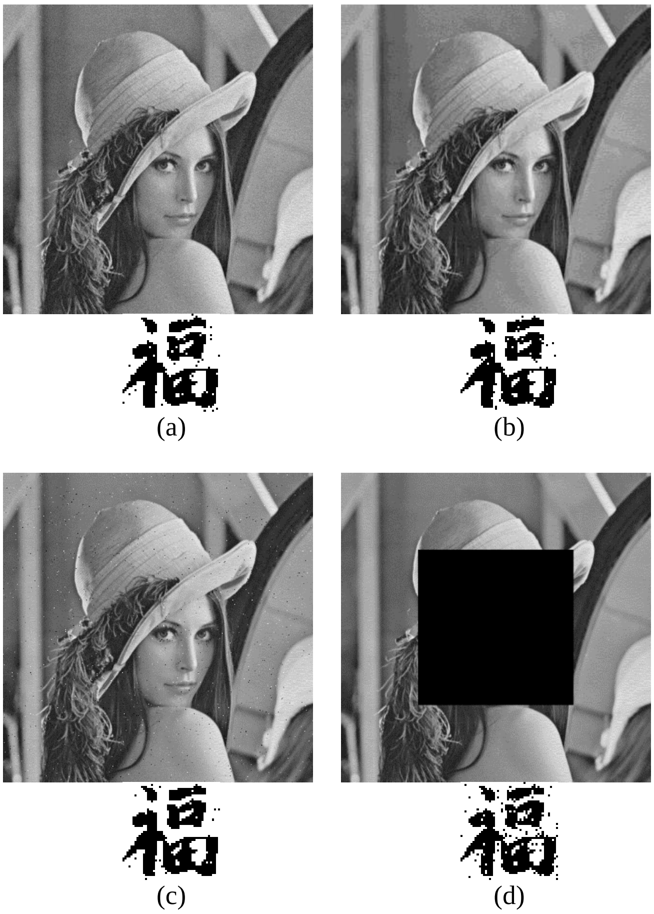

Figure 8: Attacked watermarked Lena images and watermark recovery: (a) Gaussian Noise 0.001, (b) JPEG compression, (c) Salt and Pepper 0.005, (d) Cropping centred 25%.

Table 4
Comparison of Lai's Scheme and Proposed Scheme in terms of NC Using Watermark B

Attacks	Lai's Scheme [21] T = 0.019		Propose T = 0.042	
	Baboon	Lena	Baboon	Lena
Gaussian noise 0.001	0.858	0.677	0.978	0.983
JPEG compression	0.988	0.991	0.990	0.983
Gaussian low pass filter [3 3]	0.894	0.840	0.962	0.991
Salt and pepper noise 0.005	0.912	0.866	0.970	0.978
Median filter [3 3]	0.840	0.801	0.914	0.989
Sharpening	0.943	0.881	0.994	0.988
Cropping centre 12.5%	0.920	0.985	0.906	0.995
Average	0.908	0.863	0.959	0.987

The comparison of the visual watermark recovery under different types of attacks between Lai's scheme and the proposed watermarking scheme is shown in Table 5 and Table 6. The visual perceptions of watermark recovery show the proposed scheme produces more robust than Lai's watermarking scheme. Our watermark scheme has shown successful resistance against some attacks. In addition, the watermark extraction can be recovered with high visual quality.

Table 5
Visual Comparison of the Watermark Recovery Using Watermark A

Attacks	Lai's Scheme [21] T = 0.019		Propose T = 0.042	
	Baboon	Lena	Baboon	Lena
Non-attack				
Gaussian noise 0.001				
JPEG compression				
Gaussian low pass filter [3 3]				
Salt and pepper noise 0.005				
Median filter [3 3]				
Sharpening				
Cropping centre 12.5%				

Table 6
Visual Comparison of the Watermark Recovery Using Watermark B

Attacks	Lai's Scheme [21] $T = 0.019$		Propose $T = 0.042$	
	Baboon	Lena	Baboon	Lena
Non-attack				
Gaussian noise 0.001				
JPEG compression				
Gaussian low pass filter [3 3]				
Salt and pepper noise 0.005				
Median filter [3 3]				
Sharpening				
Cropping centre 12.5%				

V. CONCLUSION

An image watermarking scheme using 4×4 DCT-SVD using modified entropy is presented. It uses a modified entropy that can help to identify un-noticeable region blocks for watermark embedding. The proposed watermarking scheme has modified the relation between $U_{2,1}$ and $U_{3,1}$ of U matrix on 4×4 DCT-SVD. It is demonstrated by experimental results that our scheme provides higher imperceptibility in the watermarked images with different watermark sizes. The watermarking scheme produces high potential resistance towards different types of attacks. This watermark scheme provides a high capacity of embedded watermarks. The watermarking scheme produces fewer errors reconstruction of the watermarked image with high structural similarity index. A watermarking scheme using 4×4 DCT-SVD using modified entropy has high-energy compaction, low-computational cost and easy to be implemented in the real watermarking applications.

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