An Improved Robust Digital Image Watermarking Algorithm based on two-level DCT

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***Abstract*—This paper presents a novel image watermarking algorithm based on Discrete Cosine Transform (DCT). To imbed the watermark, we first divide the image into non-overlapping partition. Then, after applying DCT, named as one-level DCT, to the host images blocks, and DC coefficients of each block are extracted. Next, we perform DCT again, named as two-level DCT, on the matrix comprised of the selected DC coefficients of each image blocks. Finally, the watermark is embedded on the part of the coefficients after the two-level DCT. The host signal interference (HIS) is the persistent concern in the spread spectrum principle. This paper overcomes the drawback by substituting spread spectrum watermark (SSW) for the original values. However, in the traditional way, these original values are modified by adding with SSW. Moreover, fixed-number blocks for image segmentation plays an important role in resisting scaling attacks. Experimental results demonstrate that the proposed method is resilient to many kinds of image processing attacks and geometric distortions, such as filtering, noise adding, JPEG compression, scaling, aspect ratio change and some kinds of combined transforms.**

Keywords*—*image watermarking, DCT, host signal interference, spread spectrum

I. Introduction

Digital watermarking plays an important role today for protection of digital multimedia, such as video, audio, image, text, 3D models and so on. In general, invisible watermarking can be classified into two types according to their use: robust and fragile (or semi-fragile) watermarking. The robust watermarking aims to protect copyright and ownership verification because they are resilient to many kinds of image processing attacks and geometric distortions [1-2]. Fragile watermarks are generally used for content authentication and tempering location. Here we focus on robust watermarking [3].

Over the last decade, Geometric attack is still the main challenge to robust watermarking. To defend against geometric attacks, there are four kinds of image watermarking methods proposed to resist geometric distortions according to research achievements. The first are geometric invariant domain algorithms, such as Fourier-Mellin Transformation (FMT) [4], Log-Polar Mapping (LPM) [5], Radon Transformation [6]. For these methods, the first thing they do is to transform the image into their invariant domain. The second algorithms can be called image normalization methods, which convert the images of different varieties to uniform sizes and orientations, then embed or extract watermarking there. To some extent, these algorithms can resist some kinds of geometric attacks, seriously. Moreover, the template watermarking [7] and feature points embedding [8] show better effectiveness against geometric distortions. However, there are some disadvantages in balancing robustness, invisibility and capacity.

Considering the watermark embedding positions, the watermarking approaches may be classified into spatial domain ones and transform ones. The watermarking embedded in a transform domain is generally considered more robust than those in spatial domain [9]. The most widely transforms include DCT [10, 11], discrete wavelet transform (DWT) [12], discrete Fourier transform (DFT) [13], singular value decomposition (SVD) [14], and some hybrid domain [15-17], etc.

Now, there are usually two schemes, spread spectrum and quantization modulation, to embed watermarking [9, 18-20]. Unfortunately, they suffer from host signal interference (HSI) [20] and scaling attacks [21], respectively.

This paper presents a novel robust digital image watermarking algorithm based on DCT, and an improved method to HSI. In addition, we apply fixed-number blocks to improve the resistance to geometric attacks. Experimental

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results show that the performance of our proposed method is superior to the compared algorithms.

This paper is organized as follows: In Section II, we present our improved watermark embedding and extraction algorithms. Section III gives out the experimental results. We draw our conclusion in section VI.

II. IMAGE WATERMARKING ALGORITHM

In this section, we describe how to embed and extract watermark. Fig.1 illustrates the block diagram of our two-level DCT algorithm. The following steps elaborate on the details.

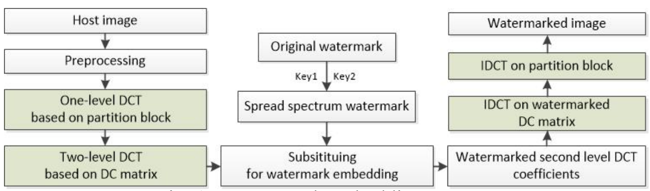

Fig. 1. Watermark embedding process

A. Watermark Embedding Algorithm

Step 1: Preprocessing

- Resize the original image proportionally
- Resize the original image disproportionally

To deal with scaling attacks, we adopt the fixed-number blocks partition [11] that results in very good resistance to some attacks to zoom the image. In our scheme, the minimum length and width of the picture for this restriction is 256. If the row or column of the image matrix is smaller than 256, an amplification operation is iterated proportionally until its height and width are greater than or equal to 256. Furthermore, if the height or width is not divisible by the number of blocks, the same operation is done.

The difference is that the image is enlarged disproportionally at this time. Meanwhile, this change only affects the image quality slightly.

Step 2: One-level DCT

- Segment the matrix into non-overlapped blocks, the total number of the blocks is 128×128 and we can obtain the height and width of each block by dividing the row and column of the matrix by 128 respectively.
- Apply DCT to all the blocks, DC coefficients of each block are extracted to form a matrix, that is to say, the generated matrix is comprised of the 128×128 DC coefficients.

The DCT converts a signal or an image from the spatial domain to the frequency domain, which can be further divided into low frequency, medium frequency and high frequency from top left to bottom right in a DCT coefficient block. The low frequency components concentrate on the most of the energy of image, in other words, the high frequency parts can be removed without affecting the image quality. This advantage is fully utilized in JPEG compression. From the perspective of watermark invisibility, the stability of the low frequency components determines its ability to resist attack, such as noise, filtering and so on. Therefore, the low frequency domain is the ideal locations to embed the watermark. In this paper, we choose DC coefficients for embedding watermark.

Step 3: Two-level DCT

- Perform the global DCT to the 128×128 coefficient matrix obtained in Step 2.
- Select the coefficients after sorting in zigzag scanning order. Since the embedded watermark bit is 128 and the spread spectrum multiple chosen is 2 times, the embedding requires 256 consecutive positions. In the proposed method, we chose the reciprocal 256 positions for embedding the watermark. Experimental results show that this selection has a better effect than other locations.

Step 4: Spread spectrum watermark

Among many existing approaches, the spread spectrum is frequently used in watermarking systems. In spread spectrum techniques, the watermarking information is spread over many samples of the host content. Here the process does exactly the transformation from a bits 0/1 watermark sequence to a random vector. A detailed procedure is presented in [11].

Step 5: Substituting

- Delete the coefficients in the selection position after two-level DCT.
- Fill these positions with the spread spectrum watermark.

Substitution means that the coefficients of the original positions are directly and completely replaced by the spread spectrum watermark. In the traditional additive spread spectrum (ASS) framework, the watermark bits (e.g., the name or logo of the copyright owner) modulated by an SS sequence are added to the watermarked signal. In fact, the signal itself is a source of interference, named host signal interference (HSI). The complete deletion thoroughly eliminates negative impact brought by the original information. The experimental results show the effectiveness of this process.

Step 6: Updating

- Do the two-level Inverse Discrete Cosine Transformation (IDCT).
- Do the one-level IDCT.
- Restore the original size of the image (if necessary).

Here, we get the watermarked image.

B. Watermark Extraction Algorithm

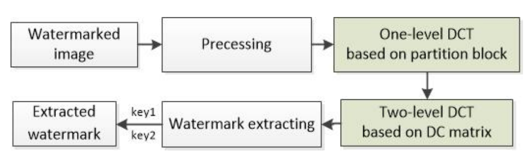

Fig. 2. Watermark extraction process

The block diagram of watermark extraction is shown in Fig.2. To put is simply, it is the inverse process of the embedding process.

Step 1: Preprocessing

Preprocess the watermarked image as the operations in Step 1 of watermark embedding process. Note that the watermarked image is likely to be distorted in a variety of attacks

Step2: One-level DCT and Two-level DCT

As described in the embedding method, we apply the one-level DCT and two-level DCT on watermarked or distorted image to get the amount or value that is actually mixed with the watermark and at the same time contaminated.

Step3: Extraction

The watermark is extracted by computing the inner product of vectors in the traditional spread spectrum techniques [11].

Now, we get the watermark.

III. Experiment Results

In this subsection, we evaluated the performance of the watermarking schemes in DWT&DCT&SVD [16], the hybrid method of SVD&DCT [17] and our proposed algorithm under no attack, image processing attacks, geometric attacks and combined attacks. The following is the introduction of the experiments and results.

A. Experimental Setup

The basic configuration for the experiment is as follows. The tested images are different gray images of size 512*512 in Fig.3. The identical original watermark, 128 bits 0/1 sequence, is embedded into these images. The imperceptibility is judged by comparing the Peak signal to noise ratio (PSNR) of the original image and with that of the watermarked image. Robustness is measured by the bit error rate (BER) and normalized correlation (NC) between the original watermark and the extracted watermark. All experiments were performed on a PC with 2.6GHz Intel Core i7 CPU and 16 GB RAM, running in 64-bit Windows 10. The software for simulations is Matlab R2017b.

B. Parameter Setup

The types of attacks and parameter setting are introduced in the following and Fig.4 illustrates part of attacked images.

Fig.3. Cover images for test

Here are parameter types for common image attacks. The watermarked images are compressed with JPEG compression ratio from 20% to 90%. The interval step is 10%. The variance of Gauss noise determines the degree of image contamination. Here they are 0.0001, 0.001 and 0.01. The density of corruption by salt & pepper noise is from 0.01 to 0.04. Average filtering means that the original pixel in watermarked images is replaced by the average value of adjacent pixels with a 3x3 mask. Median filtering is that the original pixel in watermarked images is replaced by the median value of adjacent pixels with a 3×3 mask. Histogram equalization is to apply the image's histogram to adjust the contrast of the watermarked images. Luminance change refers to change the luminance of the watermarked images by adding or subtracting directly a preset

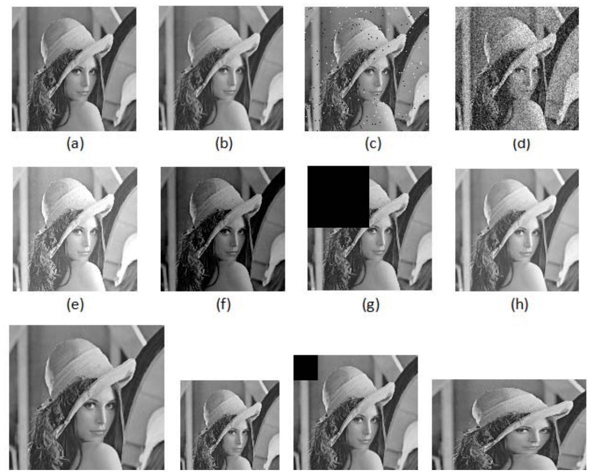

Fig.4. Watermarked image subject to:(a) Median filtering(3x) (b)Average filtering(3x3) (c)Salt & pepper noise(0.01) (d)Gauss noise(0.001) (e) Luminance change(+50) (f)Luminance change(-50) (g)Cropping(50%) (h) Averrage(3x3)+Luminance(+30) (i) Scaling(1.25)+Median(3x3) (j) Scaling(0.8) (k) Resizing(0.75)+Cropping(20%) (l) Aspect ratio change (0.8x1.4)

The following are some descriptions for some geometric attacks. The Resizing means that, after resizing the width and height of the watermarked image to 0.5 to 2.0 times the image, the attack restores the watermarked image to its original size. The Scaling attack is that the width and height of the watermarked image is scaled in equal proportions and the scaling factor is from 0.5 to 2.0. The Cropping is to replace the top left 10% to 50% of the watermarked image with zero. The Aspect ratio change is that the width and height of the watermarked image are scaled with different proportions.

The combined attacks are classified into three types. Applying two image processing attacks on the watermarked images is named Combinations of image processing attacks; The Combinations of geometric attacks is that the image is attacked by two geometric attacks; The Combinations of geometric attack and image processing attack means that the images is subject to geometric attack and processing attack.

C. Comparison of Imperceptibility

For a fair and valid comparison, the different embedding strength is selected among these methods. As a result, we get an approximately equaled PSNR. As a rule of thumb, the PSNR with a value of more than 40 dB represents decent perceptual quality [21]. The embedding strength keeps 1.46 that is the same as stated in the article [16], SVD&DCT [17] uses 50 as threshold value, whereas the strength value is set to 80 in our method.

Notice that we hold a larger PSNR, however, the ability to resist attacks is still more superior to the other ones. This means that our approach is better in both invisibility and robustness. The average PSNR of 10 images and their corresponding embedding parameters are shown in Table I.

D. Comparison of Robustness

- Robustness without attacks

The first line of Table II shows the robustness of these methods without attacks. But there still are errors in SVD&DCT [17] under the lack of any attacks. The reason is the capacity of 128 bits in this paper, yet 64 bits in [17]. The other two algorithms guarantee the exact watermark extraction in the absence of attacks.

- Robustness against image processing attacks

The types and parameters of the attacks and simulation results are listed in Table II. It is clear that our proposed method is superior to DWT&DCT&SVD [16] and SVD&DCT [17] in all scenarios. Moreover, with the increase of the attack strength, the performance of our method is much better than the other two algorithms. The reason is that we embed the watermark on low frequency coefficients and almost all image processing attacks have little effect on the DC coefficient. In addition, our method removes HIS completely. This further increases the resistance to the attacks.

The other two algorithms choose the low and medium frequencies. As a result, the performance is weaker than our method. Meanwhile, both of them use the difference quantization method to embed watermark, which increases the difficulty in the balance between invisibility and robustness.

- Robustness against geometric attacks

Table III shows the result of these methods under different geometric attacks. It is worth noting that our proposed method is prominent in scaling attack and aspect ratio change. This is due to the combination of the fixed-number blocks segmentation and spread spectrum scheme. In the other two methods, the size of the blocks is fixed, this setup makes them powerless against scaling attacks.

TABLE I. AVERAGE PSNR AND CORRESPONDING STRENGTH

Parameters	*DWT&DCT&SVD[16]*	*SVD&DCT[17]*	*Our method*
PSNR/NC	42.90/0.98	43.726/0.9853	47.67/0.9872
Embedding strength	1.46	50	80

Moreover, although the cropping attacks remove the parts of information completely, the watermark hidden in these regions can be correctly recovered. This is mainly thanks to redundant embedding for DWT&DCT&SVD [16] and SVD&DCT [17] .

The resistance to the cropping attack is guaranteed because of the advantages of spread spectrum in our proposed method. In addition, the three algorithms perform well in resizing attack, which depends on how much information of the image is missing after reducing image size and how the lost information change the parameters, which affects the correct extraction of watermark. Some reliable frequency coefficients are selected in the design of the three algorithms, this leads to their good results.

- Robustness against combined attacks

Three combinations of attacks are considered including the combinations of image processing attacks, the combinations of geometric attack, the combinations of image processing attacks and geometric attacks. The particular settings are shown in Table IV. It can be seen that the proposed method demonstrates notable robustness and consistently yields the higher NC or lower BER than the other two methods. It's no surprise to get such results because our methods have shown sufficient excellence when dealing with a certain type of attacks alone.

TABLE II. NC/BER UNDER THE IMAGE PROCESSING ATTACKS

Attacks Types	*Parameters*	*DWT&DCT&SVD[16]*	*SVD&DCT [17]*	*Our method*
Without Attack	-	1/0	0.9914/0.7031	1/0
Salt&Peppers Noise	0.0001	1/0	0.9905/0.7813	1/0
	0.001	0.9969/0.1563	0.9840/1.3281	1/0
	0.01	0.9359/3.2031	0.9387/4.9219	1/0
	0.02	0.8125/9.375	0.8623/10.781	0.9969/0.1563
Gauss Noise	0.0001	0.9969/0.1563	0.9868/1.0938	1/0
	0.001	0.9594/2.0313	0.9676/2.6563	1/0
	0.01	0.7313/13.438	0.8588/11.17	0.9766/1.1719
	0.02	0.5969/20.5969	0.7635/18.05	0.9187/4.0625
JPEG Compression	20%	0.9094/4.5313	0.9567/3.5156	0.9984/0.0781
	30%	0.9438/2.8125	0.9735/2.1875	1/0
	40%	0.9641/1.7969	0.9734/2.1875	1/0
	50%	0.9781/1.0938	0.9878/1.0156	1/0
	60%	0.9875/0.625	0.9811/1.5625	1/0
	70%	0.9969/0.1563	0.9811/1.5625	1/0
	80%	0.9984/0.0781	0.9886/0.9375	1/0
	90%	0.9984/0.0781	0.9876/1.0156	1/0
Median Filtering	3x3	0.9781/1.0938	0.9895/0.8594	0.9984/0.0781
Average Filtering	3x3	0.9781/1.0938	0.9934/0.5468	0.9984/0.0781
Histogram Equalization	-	0.9891/0.5469	0.9749/2.0313	0.9984/0.0781
Luminance change	+10	1/0	0.9914/0.7031	1/0
	+30	0.9984/0.0781	0.9904/0.7813	1/0
	+50	0.9938/0.3125	0.9718/2.3438	1/0
	-10	1/0	0.9914/0.7031	1/0
	-30	1/0	0.9943/0.4688	1/0
	-50	0.9891/0.5469	0.9764/1.9531	1/0

TABLE III. NC/BER UNDER THE GEOMETRIC ATTACKS

Attacks Types	*Parameters*	*Dwt&DCT&SVD[16]*	*SVD&DCT [17]*	*Our method*
Cropping	10%	1/0	0.9924/0.625	1/0
	20%	1/0	0.9896/0.8594	0.9906/0.4688
	30%	0.9984/0.0781	0.9915/0.7031	0.9968/0.1563
	40%	0.9906/0.4688	0.9858/1.1719	1/0
	50%	0.9563/2.1875	0.9915/0.7031	0.9891/0.5469
Resizing	100%-50%-100%	0.9984/0.0781	0.9943/0.4688	1/0
	100%-70%-100%	0.96094/1.9531	0.9832/1.4063	0.9953/0.2343
	100%-90%-100%	1/0	0.9925/0.625	1/0
	100%-120%-100%	0.9969/0.1563	0.9897/0.8594	1/0
	100%-150%-100%	1/0	0.9925/0.625	1/0
	100%-200%-100%	1/0	0.9944/0.4688	1/0
Scaling	0.5	/	/	1/0
	0.6	/	/	0.9953/0.2343
	0.8	/	/	1/0
	1.2	/	/	1/0
	1.5	/	/	1/0
	2	/	/	1/0
Aspect Ratio Change	0.7x0.8	/	/	1/0
	1.2x1.5	/	/	1/0
	0.8x1.4	/	/	1/0
	1.8x0.7	/	/	1/0
	1.7x1.1	/	/	1/0
	2.0x1.0	/	/	1/0

IV. CONCLUSION

We present a novel blind digital image watermarking algorithm based two-level DCT. The proposed method makes full use of the advantages of DCT to resist attacks, adopts the idea of fixed-number blocks to deal with the scaling attack, and exploits simple and effective substitution method to eliminate HSI that is the inherently flaw in the spread spectrum scheme. As a result, our algorithm can not only resist common image processing attacks, but also has excellent resistance to geometric distortions and their combined ones. The weakness of this method is that it has no ability to resist rotation and translation attack. In future work, we will focus on RST-invariant (rotation, scaling, and translation) digital image watermarking scheme.

TABLE IV. NC/BER UNDER THE COMBINED ATTACKS

Attacks Types	*DWT&DCT&SV[16]*	*SVD&DC[17]*	*Our method*
Resizing(100%-75%100%) +Gauss(0.001)	0.925/3.75	0.974/2.4219	1/0
Resizing(100%-125%100%) +Gauss(0.001)	0.9563/2.1875	0.9676/2.6563	1/0
Resizing(100%-75%-100%) +Salt & Peppers(0.01)	0.8844/5.7813	0.9386/4.9219	1/0
Resizing(100%-125%-100%) +Salt & Peppers(0.01)	0.9031/4.8438	0.9203/6.25	1/0
Resizing(100%-75%100%) +JPEG(0.5)	0.9688/1.5625	0.9203/1.4063	1/0
Resizing(100%-125%100%) +JPEG(0.5)	0.9797/1.0156	0.9877/1.0156	1/0
Resizing(100%-75%-100%) +Median(3x3)	0.9906/0.4687	0.9924/0.625	0.9969/ 0.1563
Resizing(100%-125%-100%) +Median(3x3)	0.9890/0.5469	0.9904/0.7813	0.9984/ 0.0781
Resizing(100%-75%-100%) +Average(3x3)	0.9890/0.5469	0.9934/0.5469	1/0
Resizing(100%-125%-100%) +Average(3x3)	0.9703/1.4844	0.9953/0.3906	1/0
Resizing(100%-75%-100%) +luminance(+30)	1/0	0.9925/0.625	1/0
Resizing(100%-125%-100%) +luminance(+30)	1/0	0.9987/0.9375	1/0
Scaling(0.75)+Gauss(0.001)	/	/	1/0
Scaling(1.25)+Gauss(0.001)	/	/	1/0
Scaling(0.75)+Salt&Peppers(0.01)	/	/	1/0
Scaling(1.25)+Salt&Peppers(0.01)	/	/	1/0
Scaling(0.75)+JPEG(0.5)	/	/	0.9984/ 0.0781
Scaling(1.25)+JPEG(0.5)	/	/	1/0
Scaling(0.75)+Median(3x3)	/	/	0.9906/ 0.4688
Scaling(1.25)+Median(3x3)	/	/	1/0
Scaling(0.75)+Average(3x3)	/	/	0.9969/ 0.1563
Scaling(1.25)+Average(3x3)	/	/	1/0
Scaling(0.75)+luminance(+30)	/	/	1/0
Scaling(1.25)+luminance(+30)	/	/	1/0
Cropping(20%)+JPEG(0.6)	0.9766/1.1719	0.9878/1.0156	0.9890/ 0.5469
Cropping(20%)+Gauss(0.001)	0.9531/2.3438	0.9521/3.9063	0.9938/ 0.3125
Cropping(20%)+Salt&Peppers(0.01)	0.9375/3.125	0.9139/6.875	1/0
Cropping(20%)+Median(3x3)	0.9719/1.4063	0.9868/1.0938	0.9844/ 0.7813
Cropping(20%)+Average(3x3)	0.96719/1.6406	0.9906/0.7813	0.9906/ 0.4688
Cropping(20%)+luminance(+30)	0.9984/0.0781	0.9986/0.9375	0.9938/ 0.3125

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REFERENCES

[1] Verma V S, Jha R K. "An Overview of Robust Digital Image Watermarking". IETE Technical Review, United Kingdom, vol. 32(6), pp. 479-496, September 2015.

[2] M. Asikuzzaman and M. R. Pickering, "An overview of digital video watermarking," IEEE Trans. Circuits Syst. Video Technol. United States, vol. 28(9), pp. 2131–2153, September 2018.

[3] Shilpi S , Debnath B , Bandyopadhyay S K . "Security on Fragile and Semi-fragile Watermarks Authentication". International Journal of Computer Applications. vol. 3, pp.23-27, 2010.

[4] J.J.K. O'Ruanaidh, T. Pun. "Rotation, Scale and Translation Invariant Digital Image Watermarking". IEEE International Conference on Image Processing (ICIP). 1997, pp.536-539.

[5] C.Y. Lin, M. Wu, J.A. Bloom, I.J. Cox, M.L. Miller, Y.M. Lui. "Rotation, Scale, and Translation Resilient Watermarking for Images". IEEE Transactions on Image Processing (TIP). vol.10, pp.767-782, 2001.

[6] D. Simito6poulos, D.E. Koutsonanos, M.G. Strintzis. "Robust Image Watermarking based on Generalized Radon Transformations". IEEE Transactions on Circuits and Systems for Video Technology (TCSVT). vol.13, pp.732-745, 2003.

[7] S. Pereira, T. Pun. "Robust Template Matching for Affine Resistant Image Watermarks". IEEE Transactions on Image Processing (TIP). United States, vol.9, pp.1123-1129, 2000.

[8] P. Bas, J.M. Chassery, B. Macq. "Geometrically invariant watermarking using feature points. IEEE Transactions on Image Processing (TIP). United States, vol.11, pp.1014-1028, 2002.

[9] I.J. Cox, J. Kilian, F.T. Leighton, T. Shamoon. "Secure Spread Spectrum Watermarking for Multimedia". IEEE Transactions on Image Processing (TIP). United States,vol.6, pp. 1673-1687, 1997.

[10] Hernandez, Juan, R, et al. "DCT-Domain Watermarking Techniques for Still Images: Detector Performance Analysis and a New Structure". IEEE Transactions on Image Processing. United States, vol.9, pp. 55-68, 2000.

[11] H. Guan, Z. Zeng, J. Liu, and S. Zhang, "A novel robust digital image watermarking algorithm based on two-level DCT," International Conference on Information Science. 2014, pp. 1804–1809 .

[12] C. Li, X. Song, Z. Liu, A. Zhang, and R. Yang, "A robust watermarking scheme based on maximum wavelet coeffificient modifification and optimal threshold technique", Journal of Electrical & Computer Engineering.vol. 2015, January 2015.

[13] Sun X C , Lu Z M , Wang Z , et al. "A geometrically robust multi-bit video watermarking algorithm based on 2-D DFT". Multimedia Tools and Applications. Netherlands, vol. 80, pp,13491-13511, April, 2021.

[14] Ansari I A, Pant M . "SVD Watermarking: Particle Swarm Optimization of Scaling Factors to Increase the Quality of Watermark". Springer India, vol.336, pp.205-214, January 2015.

[15] Hu HT, Hsu LY. "Exploring DWT-SVD-DCT feature parameters for robust multiple watermarking against JPEG and JPEG2000 compression". Computers and Electrical Engineering.United Kingdom, vol, 41, pp.52–63, 2015.

[16] Kang, X. B. , et al. "A novel hybrid of DCT and SVD in DWT domain for robust and invisible blind image watermarking with optimal embed-ding strength". Multimedia Tools and Applications. Netherlands, vol.77, pp.13197–13224, 2018.

[17] Z. Li, K.H.Yap, B.Y. Lei. "A New Blind Robust Image Watermarking Scheme in SVD-DCT Composite Domain". IEEE International Conference on Image Processing (ICIP). 2011, pp.2757-2760.

[18] Chen B , Wornell G W . "Quantization index modulation: a class of provably good methods for digital watermarking and information embedding". IEEE Transactions on Information Theory. United States, vol. 47, pp.1423-1443, 2001.

[19] X. Zhu, J. Ding, H. Dong, K. Hu, and X. Zhang, "Normalized correlation based quantization modulation for robust watermarking," IEEE Transactions Multimedia. United States, vol. 16, no. 7, pp. 1888–1904, November 2014.

[20] A. Valizadeh and Z. J. Wang, "Correlation-and-bit-aware spread spectrum embedding for data hiding", IEEE Transactions on Information Forensics and Security. United States, vol. 6, no. 2, pp. 267–282, June 2011.

[21] T. Huynh-The, O. Banos, S. Lee, Y. Yoon, and T. Le-Tien, "Improving digital image watermarking by means of optimal channel selection", Expert Systems with Applications. United Kingdom, vol. 62, pp. 177–189, 2016.