

A DWT based Dual Image Watermarking Technique for Authenticity and Watermark Protection

Shikha Tripathi¹, Nishanth Ramesh², Bernito A³, Neeraj K J⁴

¹Dept. of Electronics & Communication Engineering, Amrita Vishwa Vidyapeetham, School of Engineering, Bangalore, India.

shikha.eee@gmail.com

²Programmer Analyst Trainee, Cognizant Technology Solutions, Coimbatore, India.

nishanthr3105@gmail.com

³Bernito A, Graduate student, Remote Sensing, Department of Civil Engineering, Anna University, Tirunelveli, India.

bernitoxavier@gmail.com

⁴Programmer Analyst Trainee, Cognizant Technology Solutions, Bangalore, India.

nkj.neeraj@gmail.com

Abstract

In this paper we propose a DWT based dual watermarking technique wherein both blind and non-blind algorithms are used for the copyright protection of the cover/host image and the watermark respectively. We use the concept of embedding two watermarks into the cover image by actually embedding only one, to authenticate the source image and protect the watermark simultaneously. Here the DWT coefficients of the primary watermark (logo) are modified using another smaller secondary binary image (sign) and the mid-frequency coefficients of the cover/host image. Since the watermark has some features of host image embedded in it, the security is increased two-fold and it also protects the watermark from any misuse or copy attack. For this purpose a new pseudorandom generator based on the mathematical constant π has been developed and used successfully in various stages of the algorithm. We have also proposed a new approach of applying pseudo-randomness in selecting the watermark pixel values for embedding in the cover image. In all the existing techniques the randomness is incorporated in selecting the location to embed the watermark. This makes the embedding process more unpredictable. The cover image which is watermarked with the signed-logo is subjected to various attacks like cropping, rotation, JPEG compression, scaling and noising. From the results it has been found that it is very robust and has good invisibility as well.

Keywords

Dual Watermark; Discrete Wavelet Transform (DWT), Signed-Logo; Peak Signal to Noise Ratio (PSNR); Mean Square Error (MSE).

1. INTRODUCTION

The proliferation of digitized media due to the rapid growth of networked multimedia systems has created an urgent need for copyright enforcement technologies that can protect copyright ownership of multimedia objects. Digital rights management (DRM) is a generic term for access control technologies that can be used by hardware manufacturers, publishers, copyright holders and individuals to impose limitations on the usage of digital content and devices. The term is used

to describe any technology that inhibits use of digital content not desired or intended by the content provider. Over the past few years the technology of digital watermarking has emerged as a leading candidate that can solve the fundamental problem of legal ownership [1]. Applications include copyright protection, authentication and data hiding. Though watermarking is generally used to protect copyright of digital content, it is now finding use in other kinds of media like printed materials, texture images, designs, copy machines, scanners and other applications where copyright protection is required. Various watermarking schemes have been developed which embed the watermark either in spatial or in the transform domain [2]-[4].

The concept of dual watermarking, wherein, two watermarks are embedded instead of one for increased protection and security has been proposed earlier in both spatial and transform domains [5]-[8], [15]-[22]. In this paper, Discrete Wavelet Transform (DWT) domain is used and the watermark is embedded in the mid-frequency region, in order to achieve perceptual invisibility as well as robustness to attacks [9].

A new concept of embedding two watermarks into the cover image by actually embedding only one is introduced here, wherein features from the host image as well as the secondary watermark are used. This is carried out by modifying the DWT coefficients of the primary watermark (a grayscale logo/image) based on another meaningful secondary binary image (the sign) and some statistical features of the cover image, prior to embedding into the cover image. The *sign* is virtually embedded into the cover image through the *logo* i.e. the *signed-logo* is embedded into the cover image.

A new approach for embedding is proposed, wherein, the watermark pixels are chosen pseudo-randomly, besides pseudo-randomly selecting the locations for embedding the watermark in the mid-frequency region of the source image. This increases the security two-fold. The highlight of the process is that we incorporate both blind and non-blind methods into one watermarking scheme i.e. the *sign* is embedded into the *logo* in a non-blind fashion to create a *signed-logo* which is then embedded into the cover image in a blind fashion. Thus we achieve a two-level security by actually using only one watermark. Moreover in any watermarking scheme, the watermark is also an official property of the embedding authority. The concept of *signing* the watermark rules out any possibility of malicious use of the watermark. The original logo is available only to the authentic receivers. The standard deviation of the second level and first level mid-frequency coefficients of the cover image are used in both blind and non-blind methods respectively [10]-[11].

To further increase the security a pseudo random number generator (PRNG) is used at various instances in the algorithm. This reduces the chances of watermark extraction by prediction. We have developed a PRNG based on the universal constant π [12].

The proposed watermarking scheme can be made intelligent by adding an adaptive fuzzy logic interface to judge the strength of watermark and optimize the watermark embedding process which forms the future scope of this work.

The rest of the paper is organized as follows. Section 2 describes the pseudo-random number generator and Section 3 describes the non-blind embedding algorithm. Section 4 discusses blind embedding algorithm. In Section 5 we explain the watermark extraction operation. In Section 6 we present the experimental results and conclude in Section 7.

1. PSEUDO RANDOM GENERATOR

A pseudo random generator based on π is proposed and used in the embedding and extraction process. The value of π is known to be a series of continuous and random numbers occurring in a non-repetitive fashion. This pseudo random generator is used in determining the subblock locations and also in selecting the pixel values of the watermark which are to be embedded/extracted. The random number is generated as follows:

$$\begin{aligned} x(k) &= \pi(M) + i \\ M &= M + j \end{aligned} \quad (1)$$

where, $x(k)$ represents the selected number, M is the key used (K1, K2, K3, K4, K5), $\pi(M)$ is M^{th} position of real part of π and i & j are the variable loop parameters. This makes the selections more random and unpredictable. The randomness obtained by this pseudo random generator is very good and proves resistant to most of the attacks.

3. NON BLIND EMBEDDING ALGORITHM

The sign ($p \times q$ binary image) is embedded into the logo ($m \times n$ grayscale image) as follows: Firstly the original logo is divided into various subblocks and pxq subblocks are chosen pseudo-randomly for embedding each bit of the *sign*. Each subblock is decomposed into single level of DWT.

For any i^{th} subblock S_i , all the wavelet coefficients of LH and HL subbands are raised or lowered by a value K depending on the bit $\text{sign}(i)$.

$$\text{If } \text{sign}(i)=0 \quad \text{then } C_i(x,y) = C_i(x,y) - K_i \quad (2)$$

$$\text{Else if } \text{sign}(i)=1 \quad \text{Then } C_i(x,y) = C_i(x,y) + K_i \quad (3)$$

Where $C_i(x,y)$ refers to the wavelet coefficients of S_i and (x,y) corresponds to the coordinates of the wavelet coefficients of the LH and HL subbands in S_i .

The image dependent parameter K_i is derived from the standard deviation of the second level mid-frequency coefficients of the cover image. K_i is also suitably quantized in the range of wavelet coefficients C_i . IDWT is applied to all the subblocks resulting in the signed logo. This signed logo is used as the watermark for the blind embedding process.

4. BLIND EMBEDDING ALGORITHM

This algorithm makes use of the concept of thresholding. The watermark (W_m) is a $m \times n$ image and the cover image (I_m) is of size $k \times k$. The proposed algorithm uses the standard deviation of the sub-blocks to determine the threshold levels. There are 256 different threshold levels to uniquely distinguish each pixel of the grayscale watermark (8-bit resolution). The block diagram for the above process is shown in Fig. 1.

The pseudo random generator is used to linearize the watermark into a $mn \times 1$ pseudo-random sequence (L_w) using the keys K1, K2. The LH and HL subbands of I_m are used for embedding W_m . A total of mn subblocks are chosen pseudo-randomly from LH and HL subbands using the key K5.

Encoding is done using the keys K3, K4 to determine the embedding location (EM, a 2D array) within each of the selected subblocks.

For any *ith* subblock

$$mean(i) = \left(\frac{1}{M-1} \right) \sum_{(x,y) \in S_i} C_i(x,y)$$

(4)

$$std(i) = \sqrt{\left(\frac{1}{M-1} \right) \sum_{(x,y) \in S_i} \{C_i(x,y) - mean(i)\}^2}$$

(5)

Where the index *i* varies from 1 to *pq* and indicates the subblock number; *M* is the total size of each subblock; *S_i* refers to *ith* subblock; *C_i(x,y)* is the DWT coefficient of the location (x,y) within the *ith* subblock. For *ith* subblock, the mean and standard deviation (std) are calculated using only (*M*-1) locations (i.e. excluding the embedding location *EM_i(x,y)*).

For finding the different threshold levels the following formula has been defined:

$$Th(j) = A * std(i) + B * j$$

(6)

Where *j* is the running index which decides the 256 unique threshold values and *A*, *B* are secret keys. Based on the value of *Lw(i)*, a value is assigned to *EM_i(x,y)* depending on the value of the corresponding threshold *Th(i)*. A parameter *Q* is used for quantization as shown:

$$EM'_i(x,y) = EM_i(x,y)/Q \quad \text{where } EM'_i(x,y) \text{ is the new value assigned to } EM_i(x,y).$$

(7)

By following the above procedure *Wm* can be uniformly embedded into the LH and HL subbands. Finally, the IDWT is taken which results in the watermarked image.

5. WATERMARK EXTRACTION

In this section we discuss the extraction procedure of the signed logo in stage 1 followed by the sign in stage 2.

5.1 Stage 1

The watermark extraction is reverse of the embedding procedure. After extracting the wavelet coefficient *C_i(x,y)* is scaled back using the quantization factor *Q*. This is used to determine the *ith* value of the extracted pseudo-randomly linearized watermark (WM) as shown below:

$$Ci(x,y) = (C*i(x,y))*Q$$

$$WM(i) = j \text{ if } C_i(x,y) \in th(j) \pm const$$

(8)

where *const* is the predetermined tolerance value which depends on the parameters *A* and *B*.

Finally the watermark (*Wm**) is recovered from the above pseudo-random linear array (WM) using the same keys *K1*, *K2*. In some cases, the extracted coefficient may not correspond to any of the 256 thresholds calculated. This might be due to any intentional/unintentional attack on the watermarked image. In such cases the lost watermark pixels can be reconstructed with the help of the recovered neighboring pixel values. In this technique the neighboring pixel values are averaged to generate the lost value. Thus if a smooth grayscale watermark is chosen, it improves the efficiency of the watermark extraction even during attacks.

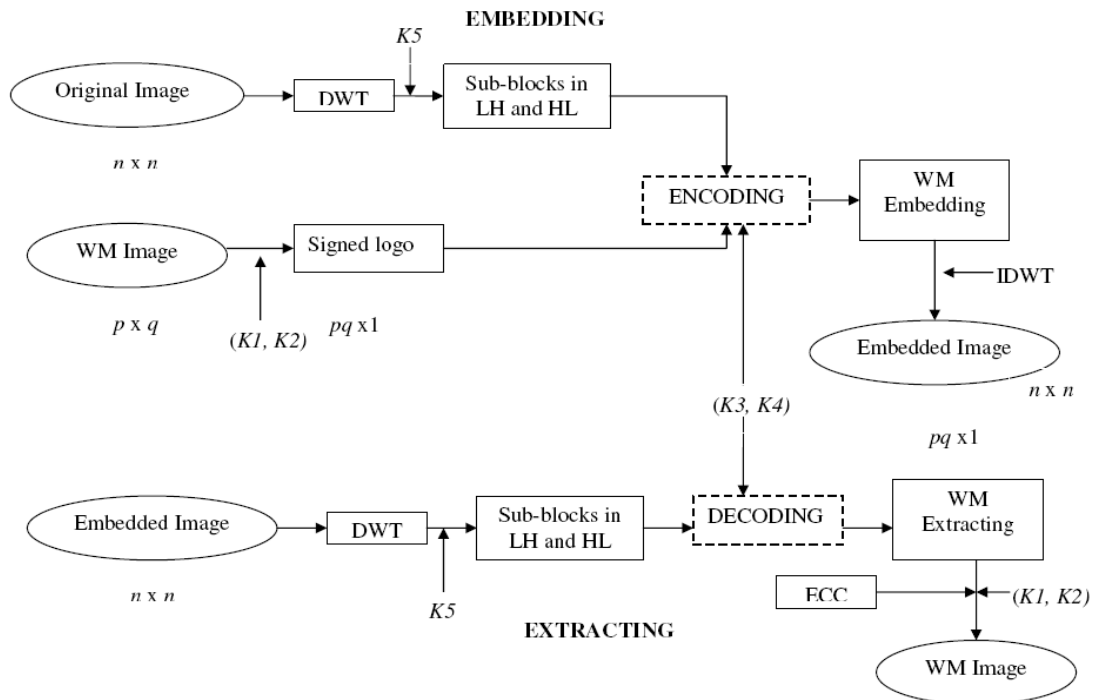


Figure 1. Block diagram to embed and extract watermark

5.2 Stage 2

From the signed logo which is obtained from stage 1 the sign is extracted using the original logo as follows:

The original logo and the extracted logo are divided into sub blocks and transformation is taken as explained in the embedding procedure. The sum of the mid-frequency coefficients of each corresponding sub block is then compared and based on their difference the sign bit is determined as follows.

If $\text{Sum}(j) > \text{Sum}^*(j)$ then the embedded bit
 $\text{sign}(j) = 0$
 else if $\text{Sum}(j) < \text{Sum}^*(j)$ then
 $\text{sign}(j) = 1$

where j refers to the sub block index and Sum and Sum^* denote the sum of all the wavelet coefficients in the LH and HL sub bands of j^{th} sub block in original and signed logo respectively. During the process of watermark embedding and extracting, the initial seeds to the pseudo-random generator $(K1, K2)$ <applied to Wm>, $K5$ <to select different sub blocks> and $(K3, K4)$ <to determine the embedding location within each sub block> are used as secret keys. The parameters A, B, Q together with the watermark size and the above mentioned initial seeds can be used as *secret keys*. It is impossible to extract the watermark without these secret keys. Furthermore the original logo can be made available only to authorized receivers who will be able to extract the sign.

6. EXPERIMENTAL RESULTS

The cover/host image used is 512x512 grayscale 'Lena' and the logo is a 64x64 grayscale image of 'Einstein'. The sign is a 16x16 binary image having the letters 'D I I A' on it. The various keys used for testing were K1=11, K2=21, K3=31, K4=41, K5=51, A=250, B=2.5 and Q=4800. The cover image which is watermarked with the signed-logo, is subjected to attacks like cropping, rotation, JPEG compression, scaling and noising. For each type of attack the results are computed for the maximum extent that can be tolerated. The metric used for evaluating the quality of extracted watermark and watermarked image is PSNR (Peak Signal to Noise Ratio).

$$PSNR = 10 * \log \left(\frac{n^2}{MSE} \right)$$

$$MSE = \frac{1}{pq} \left(\sum_{n=1}^q \sum_{m=1}^p f(m,n) - f^*(m,n)^2 \right)$$

(9)

Where pq is the size of two images f and f* whose PSNR is to be determined and n is taken to be 256.

From the results in Table I-VI, we observe that this watermarking scheme is robust to compression and other common image processing operations like cropping, rotation, scaling and noising. We also evaluate the quality by computing their corresponding Correlation Factor, which is given by,

$$\rho(w, \hat{w}) = \frac{\sum_{i=1}^N w_i \hat{w}_i}{\sqrt{\sum_{i=1}^N w_i^2} \sqrt{\sum_{i=1}^N \hat{w}_i^2}}$$

(10)

where w is the original image and \hat{w} is the extracted image. N is the total number of pixels present in the image. Correlation Factor takes values between 0 & 1. A Correlation factor of 0.75 or more is acceptable [13].

Fig. 2 shows the result of the proposed technique without any attack. The extracted cover image and sign have good PSNR & the watermark is imperceptible in the watermarked image.


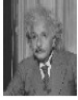

	Attacked Cover Image	Extracted Watermark (Signed-Logo)	Extracted Sign
No Attack			
PSNR	94.5200	81.8496	∞

Figure 2. PSNR values of the cover image, extracted watermark and the sign

A comparative analysis is done between the proposed technique and a multi-watermarking technique suggested in [14]. This has been chosen as reference as it gives the results for various attacks and is robust. Comparison of the Correlation Factors of the watermark (*signed-logo*) extracted from the attacked watermarked cover image is done for various attacks as shown in Table IV-VIII and Fig. 3-7.

Table 1. Watermarked image under Gaussian Noise attack

Variance (Mean $\mu=0$)	PSNR Value of Attacked Watermarked Image (dB)	PSNR Value of Extracted Watermark-Signed Logo (dB)	PSNR Value of Extracted Binary Image-Sign (dB)
0.0001	86.2948	51.2669	36.0710
0.0002	81.9066	44.4806	25.5727
0.0004	76.4931	38.8409	16.8180
0.0006	73.0076	35.1401	13.6335
0.0008	70.4384	33.4871	13.1890
0.001	68.4246	31.9644	11.4629
0.003	57.9441	28.3515	8.1681
0.005	52.9219	27.7260	7.9700
0.01	46.2044	27.9153	7.2469

Table 2. Watermarked image under salt and pepper Noise attack

Noise Density, D	PSNR Value of Attacked Watermarked Image (dB)	PSNR Value of Extracted Watermark-Signed Logo (dB)	PSNR Value of Extracted Binary Image-Sign (dB)
0.01	58.4686	68.2775	55.5301
0.02	51.5530	66.0840	46.6704
0.04	44.8779	59.6047	39.4357
0.06	40.8263	51.4966	34.7356
0.08	37.8928	49.2969	27.8042
0.1	35.6928	46.2034	22.5717
0.2	28.7313	38.6795	15.8271
0.3	24.6130	34.8198	9.1828
0.4	21.7747	30.8979	8.6166
0.5	19.5789	29.7679	7.0097

Table 3. Watermarked image under speckle noise attack

Variance (Mean=0)	PSNR Value of Attacked Watermarked Image (dB)	PSNR Value of Extracted Watermark-Signed Logo (dB)	PSNR Value of Extracted Binary Image-Sign (dB)
0.0001	91.4587	64.2207	∞
0.0003	87.3789	53.8897	39.4357
0.0005	84.4708	48.7798	25.5727
0.001	79.6009	42.3616	20.2664
0.002	73.8684	36.3294	15.8271
0.004	67.6006	32.8722	11.8356
0.006	63.7326	30.6790	10.8710
0.008	61.0107	30.1155	9.8866
0.01	58.9028	29.9199	8.9904
0.02	52.1102	29.0886	8.0807
0.04	45.5115	28.9902	7.5721
0.06	41.6675	29.5646	7.2469
0.08	38.9854	29.1705	7.2469
0.1	36.9203	29.4981	6.8547

Table 4. Watermarked image under cropping attack

CROPPED AREA	PROPOSED TECHNIQUE (Correlation Factors)		REFERENCE PAPER[8] (Correlation Factors)	
	Cropping Out	Cropping In	DCT DOMAIN	DWT DOMAIN
128x128	0.9847	0.9953	0.9494	0.4172
120x120	0.9852	0.9949	0.9043	0.4185
100x100	0.9869	0.9936	0.8627	0.4190
80x80	0.9889	0.9920	0.7590	0.4270
64x64	0.9905	0.9902	0.7221	0.4299
32x32	0.9946	0.9854	0.7045	0.4355

Table 5. Watermarked image under jpeg compression attack

COMPRESSION RATIO	PROPOSED TECHNIQUE (Correlation Factor)	REFERENCE PAPER[8] (Correlation Factor)	
		DCT DOMAIN	DWT DOMAIN
10%	0.8015	0.9242	0.4172
20%	0.9586	0.9307	0.4180
30%	0.9798	0.9599	0.4195
40%	0.9909	0.9310	0.4210
50%	0.9953	0.9488	0.4250
60%	0.9979	0.7845	0.4310
70%	0.9979	0.7810	0.4330
NO COMPRESSION	1	0.9494	0.4172

Table 6. Watermarked image under rotation attack

ANGLE (in degrees)	PROPOSED TECHNIQUE (Correlation Factor)	REFERENCE PAPER[8] (Correlation Factor)	
		DCT DOMAIN	DWT DOMAIN
350	0.7478	0.4840	0.4392
355	0.7527	-	-
0	1	0.9494	0.4172
5	0.7496	0.8415	0.4192
10	0.7387	0.6710	0.4242
20	0.7278	0.5741	0.4292

Table 7. Watermarked image under scaling attack

SCALING FACTOR	PROPOSED TECHNIQUE (Correlation Factor)	REFERENCE PAPER[8] (Correlation Factor)	
		DCT DOMIAN	DWT DOMAIN
0.5	0.3137	0.5812	0.3545
0.6	0.3981	0.6910	0.3930
0.7	0.4610	0.8312	0.4125
0.8	0.5665	0.9065	0.4155
0.9	0.6237	-	-
1.0	0.9993	0.9194	0.4172
1.1	0.7210	0.9291	0.4214
1.2	0.7218	0.9361	0.4310
1.3	0.6981	0.9390	0.4425
1.4	0.7028	0.9410	0.4410
1.5	0.7031	0.9412	0.4525

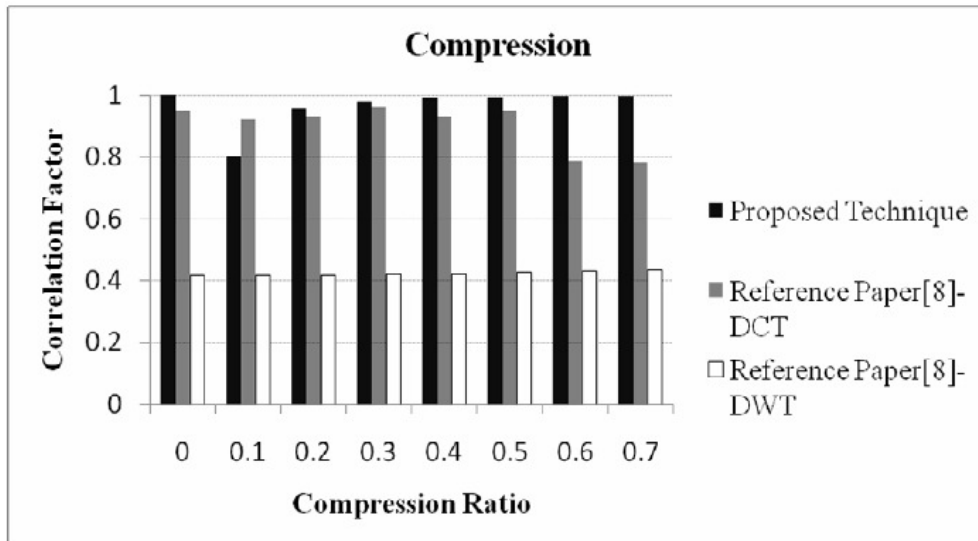


Figure 3. Comparison under compression attack

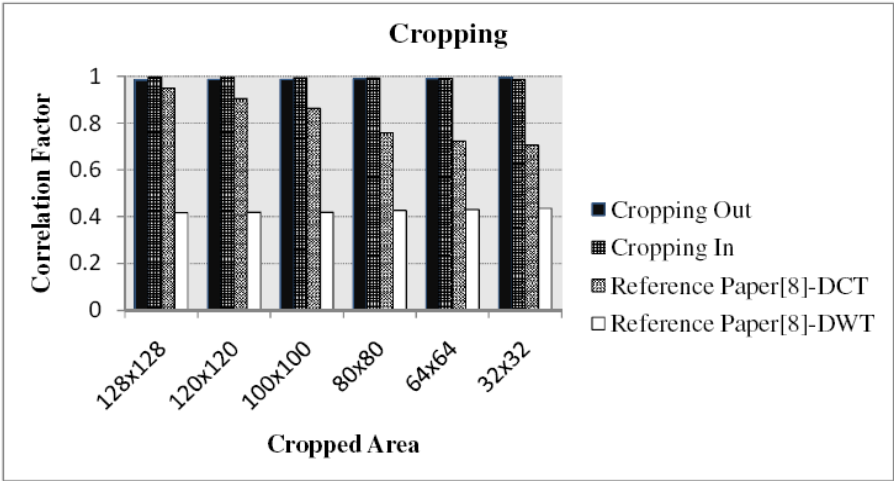


Figure 4. Comparison under cropping attack

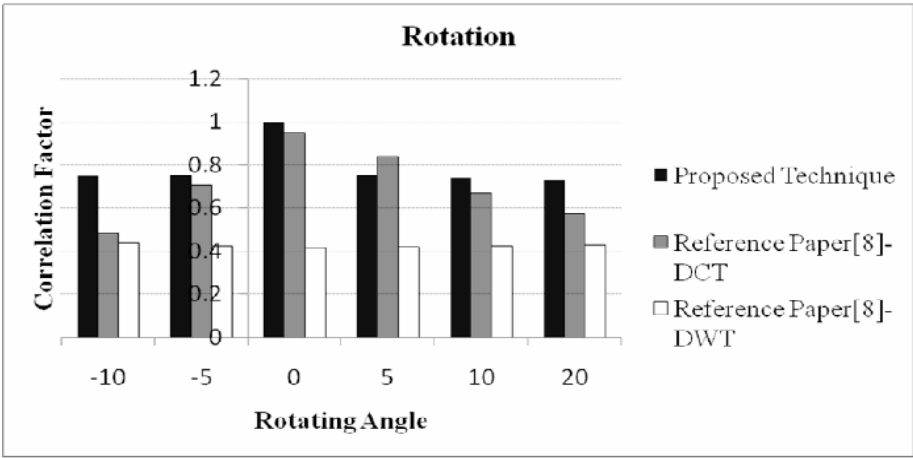


Figure 5. Comparison under rotating attack

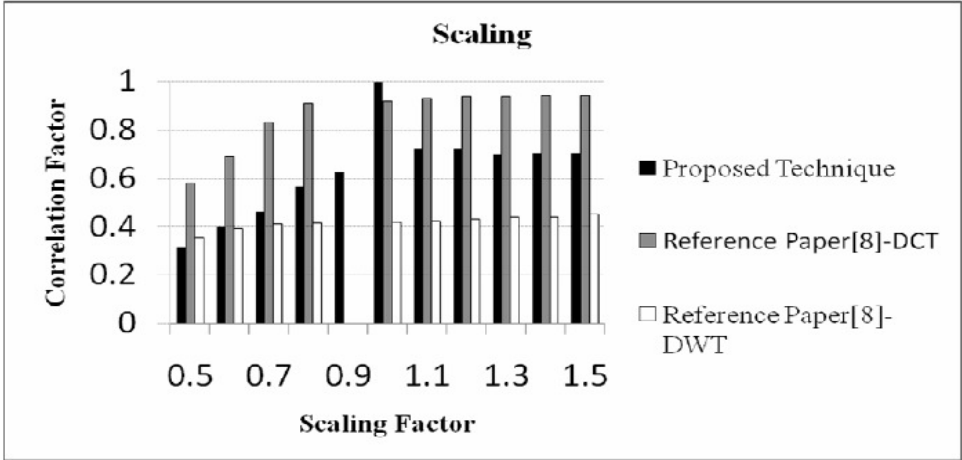


Figure 6. Comparison under scaling attack

7. CONCLUSION

In this paper a new DWT based watermarking scheme is proposed which makes use of both blind and non-blind algorithms. The highlight of the algorithm is that besides protecting the copyright of the host image it also protects the watermark from any misuse. Since the embedding process uses data from the source image as well, the extraction of watermark by an unauthorized person is not possible. It thus serves the twin purpose of providing copyright protection to the watermark and increasing the security of the whole process. For this purpose a new pseudo random generator based on the mathematical constant π has been developed and used successfully at various stages in the algorithm. The new concept of applying pseudo randomness in selecting the watermark pixels makes the process more resistant to attacks. In the proposed technique the randomness is also incorporated in selecting the location to embed the watermark. The watermarked image was tested under various attacks and the results show that the proposed technique is better than the contemporary techniques. Also the dependency of the watermark on the cover image makes the technique resistant to copy attacks. Results show that the method is resistant to most of the commonly occurring attacks.

The proposed technique can be made more robust by introducing the concept of Fuzzy Logic, Adaptive Fuzzy Logic or Neural Networks. In this method, fuzzy Logic can be used instead of pseudo-random approach, in the selection of the subblocks, where the watermark pixels are to be embedded.

REFERENCES

- [1] C I Podilbuk and E. J. Delp, (2001) "Digital watermarking: Algorithms and applications", *IEEE Signal Processing Magazine*, Vol. 18, No.4, pp33-46.
- [2] Darko Kirovski, Henrique S. Malvar and Yacov Yacobi,(2002) "Multimedia Content Screening using a Dual Watermarking and Fingerprinting System", *Proceedings of the tenth ACM international conference on Multimedia*, pp.372 – 381.
- [3] Sung Jin Lim, Hae Min Moon, Seung-Hoon Chae, Sung Bum Pan, Yongwha Chung and Min Hyuk Chang, (2008), "Dual Watermarking Method for Integrity of Medical Images", *Second International Conference on Future Generation Communication and Networking*, IEEE Computer Society, pp. 70-73.
- [4] Mingyi Jiang, Giiopiiiig Xo, Dongfeiiig Yuan, (2004) "A Novel Blind Watermarking Algorithm Based on Multiband Wavelet Transform", *Proceedings of ICSP*, pp. 857-860.
- [5] Saraju P.Mohanty, K.R. Ramakrishnan and Mohan Kankanhalli,(1999) "A Dual Watermarking Technique for Images", *Proceedings of the 7th ACM International Multimedia Conference*, pp. 49-51.
- [6] Maha Sharkas, Dahlia ElShafie, and Nadder Hamdy, (2005) "A Dual Digital-Image Watermarking Technique", *World Academy of Science, Engineering and Technology* 5, pp. 136-139.
- [7] Mathias Schlauweg, Dima Pröfrock, Benedikt Zeibich and Erika Müller, (2006) "Dual Watermarking for Protection of Rightful Ownership and Secure Image Authentication", *MCPS'06*, Santa Barbara, California, USA, pp. 59-66, October.
- [8] R.Dhanalakshmi, K.Thaiyalnayaki, (2010) "Dual Watermarking Scheme with Encryption", (*IJCSIS International Journal of Computer Science and Information Security*, Vol. 7, No. 1, pp. 248-253.
- [9] A. Miyazaki, A. Okamoto. (2002) "Analysis of watermarking systems in the frequency domain and its application to design of robust watermarking systems", *IEICE Trans.*, Vol E85, No 1, pp.117-124.

- [10] P. Meerwald and A. Uhl, (2001) "A Survey of wavelet-Domain watermarking Algorithms", *Proceedings of SPIE Security and Watermarking of multimedia Content 111*, San Jose,CA,Vol.4314, pp. 505-516.
- [11] Zhang Guannan, Wang Shuxun and Nian Guijun, (2004) "A Blind Watermarking Algorithm Based on DWT Color Image", *Intl. Symposium on Multi-Dimensional Mobile Communications*, Vol. 2,pp. 634-638.
- [12] Alfred J. Menezes, Paul C. van Oorschot, Scott A. Vanstone, (1997) "Handbook of applied cryptography", *CRC Press LLC*, ISBN 0-8493-8523-7, pp.169-190.
- [13] Ali Al-Haj, (2007) "Combined DWT-DCT Digital Image Processing", *Journal of Computer Sciences, Science Publications*.
- [14] S.M. Mohidul Islam, Rameshwar Debnath, S.K. Alamgir Hossain, (2007) "DWT Based Digital Watermarking Technique and its Robustness on Image Rotation, Scaling, JPEG Compression, Cropping and Multiple Watermarking," *ICICT*.
- [15] Peining Tao, Ahmet M. Eskicioglu, (2004) "A Robust Multiple Watermarking scheme in Discrete Wavelet Transform domain", *Optics East*.
- [16] Maha Sharkas, Dahlia ElShafie, Nadder Hamdy, (2005) "A Dual Digital-Image Watermarking Technique", *World Academy of Science, Engineering and Technology*.
- [17] R Dhanalakshmi, K Thaiyalnayaki, (2010) "Dual Watermarking Scheme with Encryption", *International Journal of Computer Science and Information Security*, Vol. 7, No. 1.
- [18] Saeed K Amirgholipour, Ahmad R. Naghsh-Nilchi, (2009) "Robust Digital Image Watermarking based on joint DWT-DCT", *International Journal of Digital Content Technology and its Applications*, Vol. 3, No. 2.
- [19] V. Santhi, Dr. Arunkumar Thangavelu, (2009) "DWT-SVD combined Full Band Robust Watermarking Technique for color Images in YUV color space", *International Journal of Computer Theory and Engineering*.
- [20] Wei Xia, Hongwei Lu, Yizhu Zhao, (2010) "A Dual Binary Image Watermarking Based on Wavelet Domain and Pixel Distribution Features", *Springer-Verlag Berlin Heidelberg*.
- [21] Pankaj U Lande, Sanjay N. Tablar, G.N. Shinde, (2010) "A Fuzzy logic approach to encrypted Watermarking for still Images in Wavelet domain on FPGA", *International Journal of Signal Processing, Image Processing and Pattern Recognition*.
- [22] Hung-H. Tsai, Chi-C. Liu, Kuo-C. Wang, (2007) "Blind Wavelet-based Image Watermarking based on HVS and Neural Networks".



Dr. Shikha Tripathi joined Amrita Vishwa Vidyapeetham, School of Engineering, Bangalore campus in July 2009. Currently, she is serving as Associate professor & Vice-Chair, Dept. of Electronics and Communication Engineering. Prior to this she was working as Group leader (Head), Electronics & Instrumentation Group at BITS Pilani. She was at BITS, Pilani from January 1998 to July 2009. Prior to joining BITS, Pilani, she was in Tata Consultancy Services, Mumbai as Assistant System

Analyst during Sept 1992 and Aug 1993 and Faculty Member, Department of Electronics & Communication Engineering, Bangalore University during Jan 1994 to Dec 1997.

Her research interests include Image Compression, image watermarking, Digital Signal/image Processing, document image processing, reconfigurable architectures for Software Defined Radio (SDR) and skew estimation techniques in document images. Currently she is working on speaker/face recognition techniques.



Nishanth Ramesh was born on May 31, 1988 in Mysore District in India. He attained Bachelor of Technology in Electronics and Communication Engineering from Amrita Vishwa Vidyapeetam, Amrita University-Bangalore in 2010. Presently he is working as 'Programmer Analyst Trainee' in 'Cognizant Technology Solutions', Coimbatore. His research interests are Signal Processing, Image Processing, Digital Watermarking.



Bernito A was born on July 29, 1988 in Kanyakumari district in India. He attained his Bachelor of Technology in Electronics and Communication from Amrita University, Bengaluru in 2010. Presently he is pursuing his Master of Technology in Remote Sensing in Anna University of Technology, Tirunelveli. His areas of interest are Digital Image Processing, Digital Image Watermarking, Interpretation of satellite images and Hyperspectral Imaging.



Neeraj Kannoth Jayraj was born on January 13, 1989 in Kasargode(Dt), Kerala. He did his schooling in Chinmaya Vidyalaya, Trissur. He completed Bachelor of Technology in Electronics and Communication from Amrita University, Bengaluru in 2010. Currently he is working in 'Cognizant Technology Solutions', Bengaluru as 'Programmer Analyst Trainee'.