HYBRID WATERMARKING OF COLOR IMAGES USING DCT-WAVELET, DCT AND SVD

H. B. Kekre[1] and Tanuja Sarode[2] and Shachi Natu[3]
[1]MPSTME, Department of Computer Engineering, NMIMS University, Mumbai, India
[2]Department of Computer Engineering, TSEC, Mumbai University, India
[3]Ph. D. Research Scholar, MPSTME, NMIMS University, Mumbai, India

ABSTRACT

*This paper presents a technique of digital image watermarking using DCT wavelet transform. Use of Haar wavelet is very common in watermarking. However, here DCT wavelet transform of size 256*256 is generated using existing well known orthogonal transform DCT of dimension 128*128 and 2*2. This DCT Wavelet transform is used in combination with the orthogonal transform DCT and SVD to increase the robustness of watermarking. HL2 sub-band is selected for watermark embedding. Performance of the proposed watermarking scheme is evaluated against various image processing attacks like contrast stretching, image cropping, resizing, histogram equalization and Gaussian noise. DCT wavelet transform performs better than our previously proposed DWT-DCT-SVD based watermarking scheme wherein Haar functions are used as basis functions for wavelet transform.*

KEYWORDS: *DCT wavelet, DCT, SVD, digital watermarking*

I. INTRODUCTION

Internet has made life of human beings easy. It has become a major way of communication and information exchange between people across the globe. The majority of communication is in the form of exchange of multimedia contents like images, audio, video etc. Security of these transferred contents is a major issue and authentication of digital contents is one of the basic requirements in providing security. Authentication is required to prevent theft, illegal alteration or illegal copying of digital contents, content labeling etc. Digital Watermarking is one of the most popular techniques used for this. Watermarking hides secret information in the signal/information to be sent over internet. This process is called watermark embedding. The signal, in which secret information is embedded, is called as cover signal or host signal and the information hidden in host signal is a watermark. Host signal can be a digital image, audio signal or video information, depending on which the watermarking is categorized into digital image watermarking, audio watermarking or video watermarking. Watermark can be a sequence of randomly generated real numbers or a picture representing a company logo or other copyright information embedded into cover image [1]. If the watermark embedded in host image is visible, it is visible watermarking and invisible watermarking otherwise. For digital image watermarking, another criteria for watermarking classification is the domain in which watermark is embedded i.e. spatial domain or frequency domain. In spatial domain, watermark embedding is done by directly modifying pixel values of an image. In frequency domain watermarking, image is first transformed into its frequency components and then appropriate frequency components are selected for embedding watermark. Recovering embedded watermark from watermarked image is called as watermark extraction. Watermarking techniques can be evaluated for performance based on their response to various intentional and non-intentional attacks. Spatial domain watermarking techniques are easier to perform than frequency domain watermarking techniques but at the same time it is more susceptible to various image processing attacks. Frequency domain watermarking techniques are more robust but complex in operation. However, this complexity is affordable as compared to spatial domain watermarking techniques and hence has grown in popularity. Use of various orthogonal and non-orthogonal transforms was initially popular for frequency domain watermarking techniques, but introduction of wavelets has changed the scenario. Wavelets help to explore certain local properties of an image whereas orthogonal/non-orthogonal transforms focus on global properties of an image. This feature of wavelets has generated an evergreen area for research in watermarking field. Discrete Wavelet Transform (DWT) has been widely used for digital watermarking in combination with other transforms like Discrete Cosine Transform (DCT), and Singular Value Decomposition (SVD) [1], [2], [3]. A good watermarking technique is supposed to have following characteristics:

Imperceptibility: Watermark embedded in the cover image should not be visible and should not tamper the quality of cover image.

Robustness: Watermark quality should not get degraded upon extraction because of various intentional and non-intentional attacks on cover image.

In this paper, a novel hybrid technique of watermarking using DCT-wavelet, DCT and SVD has been proposed. Results show that the robustness and imperceptibility of watermarking using proposed technique is much better than that of DWT-DCT-SVD based watermarking proposed in [4].

Organization of this paper is as follows: Section 2 presents work related to watermarking using various techniques. DCT and SVD and DCT-wavelet are described in Section 3. Section 4 elaborates proposed technique. Results of implementation are discussed in Section 5. Section 6 presents conclusion and further scope of work.

II. RELATED WORK

In literature, many techniques have been proposed for digital image watermarking for grayscale and colour images. Many of them are using popular transformation techniques like DCT, DWT, DFT, SVD and their combinations. Emir Ganic and Ahmet Eskicioglu [1] have proposed wavelet and SVD based watermarking scheme in which image is first divided into four frequency bands using DWT. SVD of each sub-band is then calculated. SVD values of image are then modified using SVD values of watermark. Robustness in this scheme is achieved by embedding watermark in each frequency band. This scheme is claimed to be better than embedding watermark only using SVD scheme by authors. Another Haar wavelet based watermarking scheme is proposed by Manjunatha Prasad R. and Shivaprakash Koliwad [5]. In this scheme apart from wavelet decomposition of image, image itself is also provided as an input to MD5 algorithm to generate a hash value. This hash value is used as an input to random function generator to generate a random matrix which is of image size. Binary watermark is embedded into HH sub-band using generated mask matrix. By mapping this HH sub-band to its original position and then by taking inverse Haar wavelet transform, watermarked image is obtained. A wavelet transform based digital watermarking for grayscale images is proposed by Krishnan Nallaperumal et. al. [6] in this an image is decomposed into wavelet coefficients and a visual recognizable logo is embedded in the wavelet coefficients corresponding to the points with maximum entropy. Then the relation coefficients corresponding to the pairs of first scale wavelet coefficients are embedded into middle order pair of first scale wavelet coefficients. This scheme results into good imperceptibility due to human eye insensitivity to high entropy areas. Yang Qianli and Cai Yanhong [2] have proposed a DWT-DCT based watermarking wherein image is decomposed into its wavelet coefficients up to three levels. DCT of these coefficients is taken. Watermarking components are also transformed into DCT coefficients and then embedded into DCT coefficients of wavelet transformed image. Normalized Cross Correlation is used to detect the existence of watermark and PSNR is used to test the quality of watermarked image. In a watermarking method given by Xi-Ping He and Qing-Sheng Zhu [7], the wavelet transform is applied to local sub-blocks of image extracted randomly. Watermark image is then adaptively embedded into part of the sub-band coefficients by computing their statistical characteristics. SVD-DCT based watermarking technique is proposed by Zhen Li, Kim-Hui Yap and Bai-Ying Lei [3]. In this technique first SVD of image blocks is computed. Then first few singular values are selected and DCT is applied to them. High frequency band from this SVD-DCT block is selected for watermark embedding. Koushik Pal, Goutam Ghosh and Mahua Bhattacharya [8] proposed a biomedical image watermarking scheme in which multiple copies of the same data are hidden in the cover image using bit replacement in horizontal (HL) and vertical (LH) resolution approximation image components. R. Mehul and R. Priti [9] have proposed DWT based multiple watermarking scheme in which two watermarks are embedded in low and high frequency wavelet coefficients. Because of complementary advantages and disadvantages of lower and higher sub-band watermarks, this scheme is robust against various attacks. DWT-DCT-SVD based watermarking algorithm proposed by Ben Wang, Jinkou Ding, and Qiaoyan Wen et.al. [10] uses LL band of wavelet decomposed image for watermark embedding. DCT is applied to blocks of LL band and a matrix of DC coefficients is obtained. SVD of this matrix is taken. These singular values are then modified by using singular values of watermark. Ahmed Salama, Randa Atta, Rawya Rizk, Fayez Wanes [11] have proposed a robust wavelet based watermarking technique in which watermark is embedded by adaptively adding a scaled logo to the wavelet coefficients at the third level of DWT of an image. It has been observed by authors that as level of watermarking increases, less distortion is caused in image and robustness of watermarking also increases.

III. DISCRETE COSINE TRANSFORM (DCT)

Discrete Cosine Transform (DCT) is one of the most popular orthogonal transformation techniques used in image processing. High energy compaction property of DCT is the reason. In watermarking, this property helps in deciding the location in image to embed the watermark with maximum possible robustness.

IV. SINGULAR VALUE DECOMPOSITION (SVD)

Singular Value Decomposition (SVD) decomposes an M*N image I into a product of three matrices as $I=USV^T$, where U and V are orthogonal matrices of size M*M and N*N respectively. S is a matrix of size M*N whose first r diagonal values are Eigen values of positive definite matrix I^T*I [4]. Elements of U, S or V can be selected and modified for embedding watermark into an image.

V. DCT-WAVELET [12],[13],[14],[15]

Wavelets are special mathematical functions which represent scaled and shifted copies of finite length waveform and hence can be used for analysis of signals [4]. DCT wavelet transformation matrix is generated from DCT matrix. DCT-wavelet matrix of size MN*MN can be generated from M*M and N*N size DCT matrices [9]. For example, 256*256 size DCT-wavelet matrix can be generated from 128*128 and 2*2 size DCT matrices. It can also be generated from 64*64 and 4*4, 32*32 and 8*8, 16*16 and 16*16 pairs of DCT matrices. Selection of DCT matrices pair can be done on the basis of the extent to which we want to explore the local properties of an image under processing. Let M*M (say T1) and N*N (say T2) be the pair of DCT matrix selected for generation of MN*MN DCT-wavelet matrix say T. Then, first M rows of T are generated by repeating each column of T1 N times. Next M rows of T are generated by translating 2nd row of T2 M times. Similarly, next M rows of T are generated by translating 3rd row of T2 M times. Thus by translating each row of T2, corresponding M rows of resultant T are generated. Using this method, an orthogonal wavelet transform can be generated from any orthogonal transform or from combination of orthogonal transforms.

VI. PROPOSED TECHNIQUE

In this section, watermarking technique using DCT-wavelet, DCT and SVD is proposed. These techniques have been implemented on 1.33 GHz AMD Dual Core Processor with 4 GB RAM and MATLAB 7.2.

Consider a color image I of size 256*256*8. Ten such color images are used as a set of cover images. Let W be a color image/ logo of size 128*128*8 which is used as watermark. Five such logos/images have been used as a set of watermarks for embedding. Watermarking technique has been divided into embedding algorithm and extraction algorithm. Embedding refers to hiding a watermark into cover image. Extraction refers to recovering the hidden watermark from the cover image which may have undergone various intentional or unintentional attacks.

6.1. Embedding Algorithm:

Step 1. Generate 256*256 DCT-wavelet matrix from 128*128 and 2*2 pair of DCT matrices as explained in section 3.

Step 2. Generate 128*128 DCT-wavelet matrix from 64*64 and 2*2 pair of DCT matrices.

Step 3. Generate 64*64 DCT-wavelet matrix from 32*32 and 2*2 pair of DCT matrices.

These matrices are required to obtain the wavelet transformed image from cover image and watermark image.

Step 4. Take 2-level DCT-wavelet transform of Red, Green and Blue planes of cover image separately using transformation matrices generated in step 1 and step 2.

Step 5. Select HL2 sub-band of DCT-wavelet transformed cover image and apply DCT to it.

Step 6. Arrange DCT-wavelet-DCT transformed HL2 sub-band in a zigzag manner and get four quadrants out of it.

Step 7. Decompose these four quadrants using SVD and get singular values of each quadrant.

Step 8. Take 2-level DCT-wavelet transform of Red, Green and Blue planes of watermark image separately using transformation matrices generated in step 2 and step 3.

Step 9. Select HL2 sub-band of DCT-wavelet transformed watermark image and apply DCT to it.

Step 10. Decompose DCT-wavelet-DCT transformed watermark image using SVD to obtain its singular values.

Step 11. Scale the singular values of watermark image obtained in step 10 by scaling factor k and add them to corresponding singular values of four quadrants of cover image obtained in step 7.

$$S'' = S + KS' \qquad (1)$$

Where, S is the singular value matrix of each quadrant, S’ is the singular value matrix of watermark and S” is the modified singular value matrix of cover image.

Step 12. Reconstruct the watermarked image by following inverse zigzag, inverse DCT and inverse 2-level DCT-wavelet in sequence.

Step 13. Calculate Mean Absolute Error (MAE) between cover image and watermarked image as a measure of imperceptibility.

6.2. Extraction algorithm:

Step 1. Take 2-level DCT-wavelet transform of Red, Green and Blue planes of watermarked image separately using transformation matrices generated in step 1 and step 2 of embedding algorithm.

Step 2. Select HL2 sub-band of DCT-wavelet transformed watermarked image and apply DCT to it.

Step 3. Arrange DCT-wavelet-DCT transformed HL2 sub-band in a zigzag manner and get four quadrants out of it.

Step 4. Decompose these four quadrants using SVD and get singular values of each quadrant.

Step 5. Extract singular values of watermark from singular values of watermarked image and singular values of cover image.

$$S' = (S'' - S)/K \qquad (2)$$

Step 6. Construct DCT coefficients of watermark using the singular values extracted in Step 5.

Step 7. Take inverse DCT and then 2-level inverse DCT-wavelet to extract watermark from watermarked image.

Step 8. Calculate Mean Absolute Error (MAE) between original watermark and extracted watermark as a major of robustness.

Figure 1 and Figure 2 below show the ten images used as cover images and five images/logos used as watermarks for implementation.

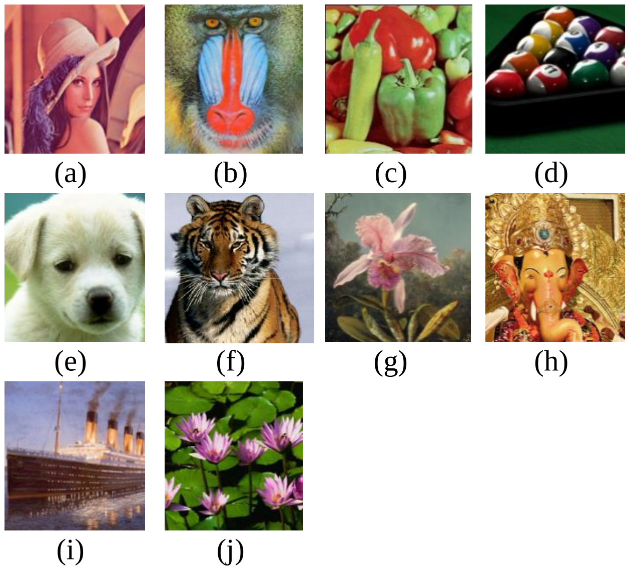


Figure 1. Cover images used for experimentation (a)Lena (b)Mandrill (c)Peppers (d)Balls (e)Puppy (f)Tiger (g)Flower (h)Ganesh (i)Titanic (j)Waterlili

Figure 2. Watermark images used for experimentation (a) Austral (b) Bear (c) CCD (d) Logo (e) NMIMS

VII. RESULTS

Table I below shows the average Mean Absolute Error between cover image and watermarked image. Each column of table corresponds to the average MAE of ten cover images for specific watermark image. These values are obtained for different scaling factors (K=0.05, 0.1, 0.2, 0.4, and 0.6).

Table 1: Average Mean Absolute Error between cover image and watermarked image for each watermark and scaling factor K

K	Watermark					Average
	Austral	bear	ccd	logo	nmims	
0.05	8.2150	8.1809	8.2254	8.1975	8.2748	8.2187
0.1	8.3122	8.2008	8.3353	8.2423	8.5027	8.3187
0.2	8.6541	8.2647	8.7156	8.3895	9.2474	8.6542
0.4	9.7735	8.4887	9.9259	8.8763	11.425	9.6979
0.6	11.2605	8.8245	11.5076	9.5454	14.0976	11.0471

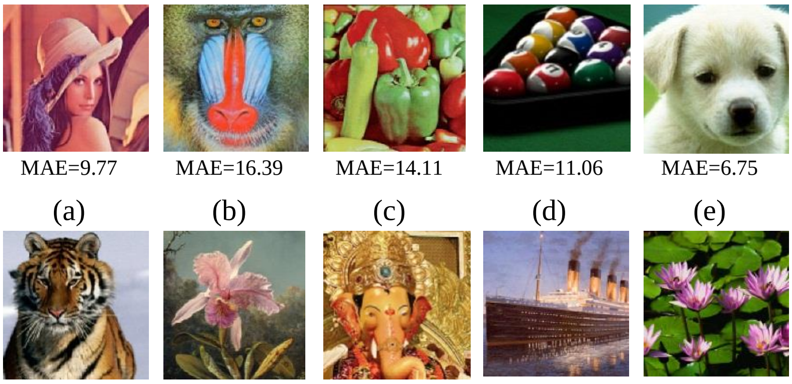
It can be observed from the Table 1 that as the scaling factor (K) value increases, Mean absolute error between cover image and watermarked image also increases. From this it can be concluded that

imperceptibility of watermarked image is dependent on selection of appropriate value of scaling factor. Lower the value of scaling factor better is the imperceptibility.
Table 2 below shows average Mean Absolute Error (MAE) between original watermark and watermarks extracted from four quadrants of HL2 sub-band of cover image for a set of ten cover images and five logos.

Table 2: Average Mean Absolute error between original and extracted watermark for five watermarks and different scaling factor (K) values

K	**Watermark**					**Average**
	austral	**bear**	**ccd**	**logo**	**nmims**	
0.05	11.2722	6.3838	9.6421	5.4784	19.0150	10.3583
0.1	11.1496	6.3136	9.4980	5.2475	18.9364	10.2290
0.2	11.1309	6.2775	9.4701	5.1743	18.9716	10.2049
0.4	11.1874	6.2735	9.5253	5.1762	19.1553	10.2636
0.6	11.2652	6.27682	9.6007	5.1955	19.3633	10.3403

From Table 2 it can be seen that MAE between original watermark and extracted watermark decreases with increased value of scaling factor till K=0.2. After this, increase in scaling factor K results into increased value of MAE. Here MAE corresponds to robustness of proposed watermarking technique. It can be concluded from the table II that beyond some threshold value of scaling factor K (K=0.2), robustness of watermarking technique decreases. Thus selection of proper scaling factor helps to achieve imperceptibility and robustness but there is a tradeoff between the two.
Figure 3 below shows the watermarked images with corresponding MAE values between cover and watermarked image for K=0.2 and watermark image ‘logo’ embedded into it.



MAE=9.77 (a) MAE=16.39 (b) MAE=14.11 (c) MAE=11.06 (d) MAE=6.75 (e)

MAE=9.31 (f) MAE=17.27 (g) MAE=30.75 (h) MAE=11.32 (i) MAE=13.98 (j)

Figure 3. Watermarked images with watermark ‘Logo’ and K=0.2

Suitability of watermarking technique is tested by performing various attacks on watermarked images viz. contrast stretching, cropping, adding Gaussian noise, histogram equalization and image resizing.
Figure 4 shows the ‘puppy’ image watermarked with ‘logo’, (K=0.2) after performing various attacks on it.

(a) (b) (c) (d) (e)

Figure 4. Watermarked ‘Puppy’ image with various attacks on it(Watermark=’Logo’, K=0.2),(a)Contrast stretching (b)Cropping (c)Gaussian noise, variance=0.1(d)Histogram Equalization(e)Resizing

Figure 5 shows the watermark 'logo' extracted from four quadrants of HL sub-band of 'puppy' image with K=0.2 for contrast stretching attack. Mean Absolute Error between original watermark and watermark extracted from each quadrant is shown below each of extracted watermark.

MAE=7.01 MAE=8.10 MAE=7.86 MAE=8.97

(a) (b) (c) (d)

Figure 5. Watermark 'logo' extracted from four quadrants of contrast stretched 'Puppy' image (a) Quadrant 1 (b) Quadrant 2 (c) Quadrant 3 (d) Quadrant 4

Table 3 shows average of MAE values between original and extracted watermark from ten cover images for contrast stretching attack. Further average of MAE is calculated for each value of scaling factor K.

Table 3: Average Mean Absolute Error between original and extracted watermark for five watermarks and different values of K when contrast stretching attack is performed

K	Watermark					Average
	austral	bear	ccd	logo	nmims	
0.05	26.927	37.652	23.866	26.144	35.729	30.064
0.1	19.258	23.265	16.918	16.399	27.502	20.669
0.2	14.926	14.103	13.152	10.604	23.019	15.161
0.4	12.806	9.403	11.358	7.708	20.982	12.451
0.6	12.170	8.009	10.820	6.815	20.449	11.653

It can be seen from Table 3 that for higher values of K, extracted watermarks show less MAE i.e. higher value of K increases robustness. However higher value of K reduces imperceptibility. Hence value of K should be such that balance in imperceptibility and robustness is achieved.

Figure 6 shows watermarks extracted from 'puppy' image after performing image cropping attack on watermarked image (K=0.2).

MAE=5.30 MAE=5.70 MAE=6.04 MAE=8.04

(a) (b) (c) (d)

Figure 6. Watermark 'logo' extracted from four quadrants of cropped 'Puppy' image (a) Quadrant 1 (b) Quadrant 2 (c) Quadrant 3 (d) Quadrant 4

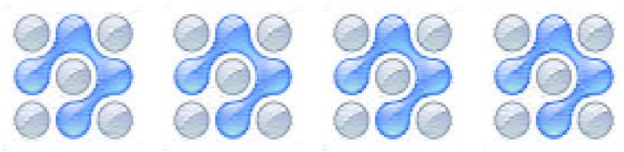
Table 4 shows average MAE values between original and extracted watermark for image cropping attack. For each watermark, average MAE is calculated over ten cover images. Average MAE value is then calculated for every value of K.

Table 4: Average Mean Absolute Error between original and extracted watermark for five watermarks and different values of K when cropping attack is performed

K	Watermark					Average
	austral	bear	ccd	logo	nmims	
0.05	16.501	13.084	14.354	10.546	24.329	15.763
0.1	13.601	9.143	11.820	7.683	21.553	12.760
0.2	12.340	7.402	10.664	6.347	20.386	11.428
0.4	11.849	6.721	10.194	5.763	20.018	10.909
0.6	11.762	6.548	10.103	5.603	20.052	10.814

From Table 4 it can be seen that as value of scaling factor K increases, MAE between original watermark and extracted watermark decreases. Thus extracted watermarks are closely correlated with original watermark.

Figure 7 shows watermarks extracted from 'puppy' image after adding Gaussian noise with 0.1 variance to watermarked image (K=0.2).



MAE=7.80 MAE=7.67 MAE=7.85 MAE=8.07

(a) (b) (c) (d)

Figure 7. Watermark 'logo' extracted from four quadrants of Gaussian noise added 'Puppy' image (a) Quadrant 1 (b) Quadrant 2 (c) Quadrant 3 (d) Quadrant 4

Table 5 shows average MAE values between original and extracted watermark when Gaussian noise (variance=0.1) is added to watermarked images. For each watermark, average MAE is calculated over ten cover images and then average MAE value is calculated for every value of K.

Table 5: Average Mean Absolute Error between original and extracted watermark for five watermarks and different values of K when Gaussian noise attack is performed

K	Watermark					Average
	Austral	bear	ccd	logo	nmims	
0.05	19.688	23.440	17.469	16.574	27.160	20.866
0.1	14.550	13.392	13.113	10.455	22.157	14.733
0.2	12.298	8.695	11.016	7.439	20.225	11.935
0.4	11.596	6.869	10.216	6.111	19.702	10.899
0.6	11.531	6.512	10.059	5.762	19.792	10.731

From Table 5, it can be seen that, MAE value decreases for increase in scaling factor (K) value. Thus more robustness can be achieved by selecting higher value of scaling factor.

Figure 8 shows watermarks extracted from 'puppy' image for histogram equalization attack on watermarked image (K=0.2).

MAE=8.27 MAE=7.32 MAE=7.04 MAE=6.86

(a) (b) (c) (d)

Figure 8: Watermark 'logo' extracted from four quadrants of histogram equalized 'Puppy' image (a) Quadrant 1 (b) Quadrant 2 (c) Quadrant 3 (d) Quadrant 4

Table 6 shows average of MAE values between original and extracted watermark from ten cover images for histogram equalization attack. Further average of MAE is calculated for each value of scaling factor K.

Table 6: Average Mean Absolute Error between original and extracted watermark for five watermarks and different values of K when histogram equalization attack is performed

K	Watermark					Average
	Austral	bear	ccd	Logo	nmims	
0.05	28.210	38.442	25.124	26.864	36.801	31.088
0.1	20.449	24.751	17.807	17.219	28.540	21.753
0.2	15.845	15.712	13.593	11.221	23.679	16.010

0.4	13.352	10.606	11.401	8.041	21.091	12.898
0.6	12.452	8.896	10.672	6.984	20.224	11.846

It is observed from Table 6 that, MAE value decreases for increase in scaling factor (K) value resulting into more robustness to a histogram equalization attack.
Figure 9 shows watermarks extracted from watermarked 'puppy' image for image resizing attack on it (K=0.2).

MAE=7.26 MAE=6.78 MAE=7.10 MAE=7.24

(a) (b) (c) (d)

Figure 9: Watermark 'logo' extracted from four quadrants of resized 'Puppy' image (a) Quadrant 1 (b) Quadrant 2 (c) Quadrant 3 (d) Quadrant 4

Table 7 shows average MAE values between original and extracted watermark when resizing of watermarked images is done. In resizing, image size (256*256) is reduced to half (128*128) of its original size using bicubic interpolation and then to original size. For each watermark, average MAE is calculated over ten cover images and then average MAE value is calculated for every value of K.

Table 7: Average Mean Absolute Error between original and extracted watermark for five watermarks and different values of K when resizing attack is performed

K	Watermark					Average
	austral	**bear**	**ccd**	**Logo**	**nmims**	
0.05	28.605	29.690	25.079	22.165	39.528	29.013
0.1	20.266	17.715	17.873	14.079	29.973	19.981
0.2	16.053	11.443	14.145	9.726	25.377	15.349
0.4	14.228	8.644	12.429	7.641	23.440	13.277
0.6	13.741	7.859	11.938	7.009	22.989	12.707

From Table 7, it is clearly visible that, MAE value decreases for increase in scaling factor (K) value.

VIII. CONCLUSION

Use of DCT-wavelet considerably improves the performance of watermarking as compared to use of Haar wavelet functions. It has been proved near about twice better in both aspects imperceptibility and robustness. Selection of appropriate value of scaling factor (K) also plays important role in proposed watermarking scheme. Higher value of K leads to more robustness against various image processing attacks but at the cost of imperceptibility. That means higher value of K causes more distortion in cover image.

IX. FUTURE WORK

Future work includes use of DCT wavelet transform generated from DCT transformation matrix of different sizes. It also includes testing performance of other wavelet transforms like Walsh wavelet, Hartley wavelet, Kekre wavelet and others generated from corresponding orthogonal transformation matrices. Further it can be expanded to use hybrid wavelet transform obtained from combination of different orthogonal transforms (e.g. DCT-Walsh wavelet). Different frequency sub-bands can also be selected for embedding watermark.

REFERENCES

[1]. Emir Ganic, Ahmet M. Eskicioglu, "Robust Embedding of visual watermarks using DWT-SVD", Journal of electronic imaging, Volume 14, issue 4.

[2]. Yang Quianli, Cai Yanhong,"A digital watermarking algorithm based on DWT and DCT", IEEE International Symposium on Information Technology in Medicine and Education, 2012, pp. 1102-1105.

[3]. Zhen Li, Kim-Hui Yap and Bai-Ying Lei, "A new blind robust image watermarking scheme in SVD-DCT composite domain", In Proc. Of 18th IEEE international conference on Image Processing, 2011, pp. 2757-2760.

[4]. H. B. Kekre, Tanuja Sarode, Shachi Natu, " Performance Comparison of DCT and Walsh Transforms for Watermarking using DWT-SVD", International Journal of Advanced Computer Science and Applications, Vol. 4, No. 2, 2013, pp. 131-141.

[5]. Manjunatha Prasad R. and Shivaprakash Koliwad, "A robust wavelet based watermarking scheme for copyright protection of digital images", IEEE Proc. Of second international conference on computing, communication and networking technologies, 2010, pp. 1-9.

[6]. Krishnan Nallaperumal, R. K. Selvakumar, S. Rajapandian et.al. , "A wavelet transform based digital image watermarking and authentication", In Proc. of IEEE Annual India Conference, 2006, pp. 1-6.

[7]. Xi-Ping and Qing-Sheng Zhu, "A robust wavelet-domain watermarking algorithm for colour image", Proceedings of the Fifth International Conference on Machine Learning and Cybernetics, Dalian, pp.13-16 August 2006.

[8]. Koushik Pal, Goutam Ghosh and Mahua Bhattacharya," Biomedical image watermarking for content protection using multiple copies of information and bit majority algorithm in wavelet domain", Electrical, Electronics and Computer Science (SCEECS), 2012 IEEE Students' Conference on,2012, pp. 1-6.

[9]. R. Mehul and R. Priti, "Discrete Wavelet Transform based multiple watermarking scheme", Proc. Of IEEE Region 10 Technical Conference on Convergent Technologies for the Asia-pacific, Banglore, India, October 2011, pp. 14-17.

[10]. Ben Wang, Jinkou Ding, Qiaoyan Wen, Xin Liao, Cuixiang Liu, "An image watermarking algorithm based on DWT DCT and SVD", In Proc. Of IEEE International Conference on Network Infrastructure and Digital Content, 2009. pp. 1034-1038.

[11]. Ahmed Salama, Randa Atta, Rawya Rizk, Fayez Wanes, "A robust digital image watermarking technique based on Wavelet transform", In Proc. Of IEEE International Conference on System Engineering and Technology, 2011, pp. 100-105.

[12]. H. B. Kekre, Tanuja Sarode, Sudeep Thepade, Sonal Shroff, "Instigation of Orthogonal Wavelet Transforms using Walsh, Cosine, Hartley, Kekre Transforms and their use in Image Compression", International Journal of Computer Science and Information Security,Vol. 9, No. 6, 2011, pp.125-13.

[13]. H. B. Kekre, Archana Patankar, Dipali Koshti, " Performance Comparison of Simple Orthogonal Transforms and Wavelet Transforms for Image Steganography", International Journal of Computer Applications (IJCA), Vol. 44, No. 6, April 2012, pp.21-28.

[14]. H.B. Kekre, Tanuja Sarode, Rekha Vig, Pranay Arya, Saurabh Bisani, Aashita Irani, "Identification of Multi-spectral Palmprints using Energy Compaction by Hybrid Wavelet", In IEEE Proc. of International Conference of Biometrics, 2012, pp.433-438.

[15]. H.B.Kekre, Archana Athwale, Dipali Sadavarti, "Algorithm to Generate Wavelet Transform from an Orthogonal Transform", International Journal of Image Processing, Vol.4, Issue 4, 2010, pp. 444-455.

AUTHORS

H. B. Kekre has received B.E. (Hons.) in Telecomm. Engg. from Jabalpur University in 1958, M.Tech (Industrial Electronics) from IIT Bombay in 1960, M.S.Engg. (Electrical Engg.) from University of Ottawa in 1965 and Ph.D. (System Identification) from IIT Bombay in 1970. He has worked Over 35 years as Faculty of Electrical Engineering and then HOD Computer Science and Engg. at IIT Bombay. After serving IIT for 35 years, he retired in 1995. After retirement from IIT, for 13 years he was working as a professor and head in the department of computer engineering and Vice principal at Thadomal Shahani Engg. College, Mumbai. Now he is senior professor at MPSTME, SVKM's NMIMS University. He has guided 17 Ph.Ds., more than 100 M.E./M.Tech and several B.E. / B.Tech projects, while in IIT and TSEC. His areas of interest are Digital Signal processing, Image Processing and Computer Networking. He has more than 450 papers in National / International Journals and Conferences to his credit. He was Senior Member of IEEE. Presently He is Fellow of IETE, Life Member of ISTE and Senior Member of International Association of Computer Science and Information Technology (IACSIT). Recently fifteen students working under his guidance have received best paper awards. Currently eight research scholars working under his guidance have been awarded Ph. D. by NMIMS (Deemed to be University). At present seven research scholars are pursuing Ph.D. program under his guidance.

Tanuja K. Sarode has received M.E. (Computer Engineering) degree from Mumbai University in 2004, Ph.D. from Mukesh Patel School of Technology, Management and Engg. SVKM's NMIMS University, Vile-Parle (W), Mumbai, INDIA. She has more than 11 years of experience in teaching. Currently working as Assistant Professor in Dept. of Computer Engineering at Thadomal Shahani Engineering College, Mumbai. She is member of International Association of Engineers (IAENG) and International Association of Computer Science and Information Technology (IACSIT). Her areas of interest are Image Processing, Signal Processing and Computer Graphics. She has 137 papers in National /International Conferences/journal to her credit.

Shachi Natu has received M.E. (Computer Engineering) degree from Mumbai University in 2010. Currently pursuing Ph.D. from NMIMS University. She has 08 years of experience in teaching. Currently working as Assistant Professor in Department of Information Technology at Thadomal Shahani Engineering College, Mumbai. Her areas of interest are Image Processing, Database Management Systems and Operating Systems. She has 12 papers in International Conferences/journal to her credit.